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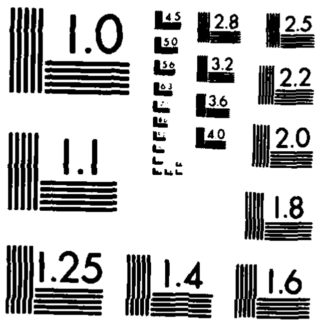
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MEMORANDUM REPORT BRL-MR-3422

FIRE SUPPORT TEAM EXPERIMENT

Jill Smith
Jock Grynovicki
Virginia Kaste
Ann McKaig
Samuel Chamberlain
Howard Walter
Hugh Dempsey
Diane Kuhl
Peter Grazaitis

December 1984

US ARMY
HUMAN ENGINEERING LABORATORY

US ARMY
BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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Jill Smith (BRL), Jock Grynovicki (BRL), Virginia Kaste (BRL),
Ann McKaig (BRL), Samuel Chamberlain (BRL), Howard Walter (BRL),
Hugh Dempsey (HEL), Diane Kuhl (HEL), Peter Grazaitis (HEL)

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US Army Ballistic Research Laboratory
ATTN: AMXBR-SECAD
Aberdeen Proving Ground, MD 21005-5066

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Artillery Control Environment (ACE), Fist Digital Message Device (DMD), Command Post Exercise Research Facility (CPXRF), Forward Observer Scenario (FOSCE), Fire Support Team Headquarters (FIST HQ), Fire Direction Center (FDC), Forward Observer (FO), Fire Direction Simulator, Mortar Fire Direction Simulator, Automatic Data Processing (ADP), Microprocessor Based Modems (Bit Box)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The Army is fielding a new digital fire direction system, the TACFIRE system, shown for the brigade-area in Figure 1. In order to investigate the command, control, and communications issues associated with the new devices, the Artillery Control Environment (ACE) was developed. ACE is a real-time, multiplayer, interactive simulation system run on a commercial computer that interfaces with the tactical equipment through a Bit Box (MODEM). This report discusses the preparations, experimental design, data collection, analysis

(Continued)

Item 20. (Cont'd)

methods, and results for the first experiment with military players interfaced with the Artillery Control Environment software conducted 8 May - 10 June 1983.

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I. INTRODUCTION

A. Background

In March 1982, the HELBAT (Human Engineering Laboratory Battalion Artillery Test) Executive Committee agreed that the Ballistic Research Laboratory Artillery Control Environment (ACE) and HELBAT activities should be combined to develop a Command Post Exercise Research Facility (CPXRF). The CPXRF technology will primarily be used for research, development, testing and evaluation (RDT&E) work in automatic data processing (ADP) fire support control systems using commercial ADP technology; a secondary usage is the training of the tactical ADP operators under controlled conditions. Further, an ACE/CPXRF Subcommittee was formed to provide joint DARCOM-TRADOC guidance in the development of ACE technology and use of the CPXRF. The ACE software is a key tool in the CPXRF. The software features the ability to automatically load live players with messages produced by target acquisition and fire direction simulators while recording all the message traffic that flows between the live and simulated players.

An overview of the CPX Research Facility and ACE program is given in the 1982 Sept-Oct issue of the Field Artillery Journal in an article "HELBAT/ACE Fire Support Control Research Facility" by Mr. Barry Reichard. The layout of the facility is shown in Figure 2.

B. Purpose

The experiment detailed in this report was the first test in which military players were interfaced with the Artillery Control Environment (ACE) software. The purpose of this experiment was to demonstrate the feasibility of using the automated techniques of the CPX Research Facility for fire support control experiments.

To demonstrate this capability, a study of the effects of message intensity and communication degradation on the Fire Support Team Headquarter's (FIST HQ) ability to perform fire support coordination, with a newly developed FIST Digital Message Device (DMD), was performed. Message intensity was defined to be a function of message type, message rate, and message content.

II. TEST CONCEPT

A. Objectives

1. To determine the effect of message intensity on the FIST HQ ability to perform fire support coordination.

2. To determine the effect of communication degradation on the FIST HQ ability to perform fire support coordination.

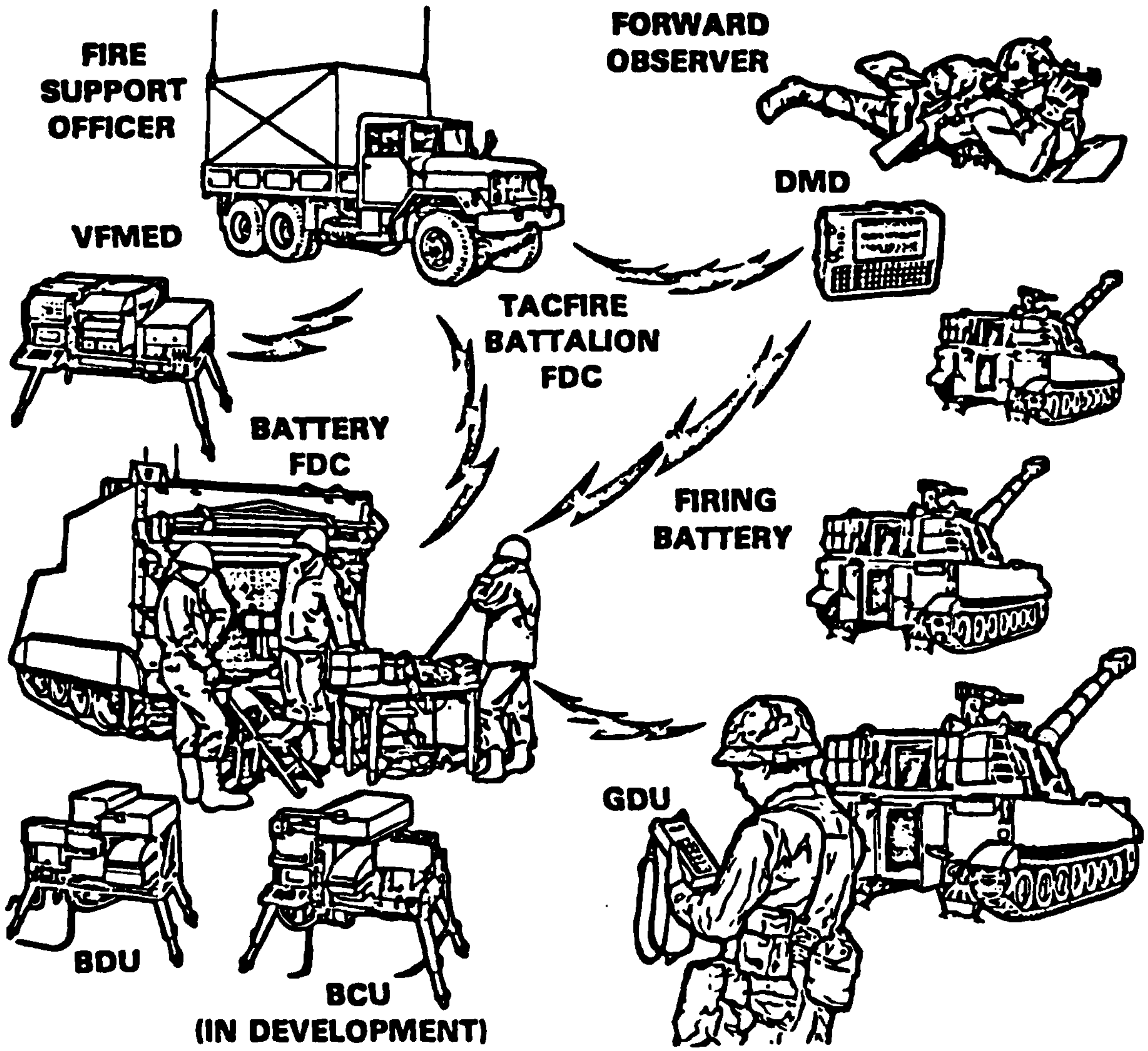

Figure 1. Brigade-Area TACFIRE System.

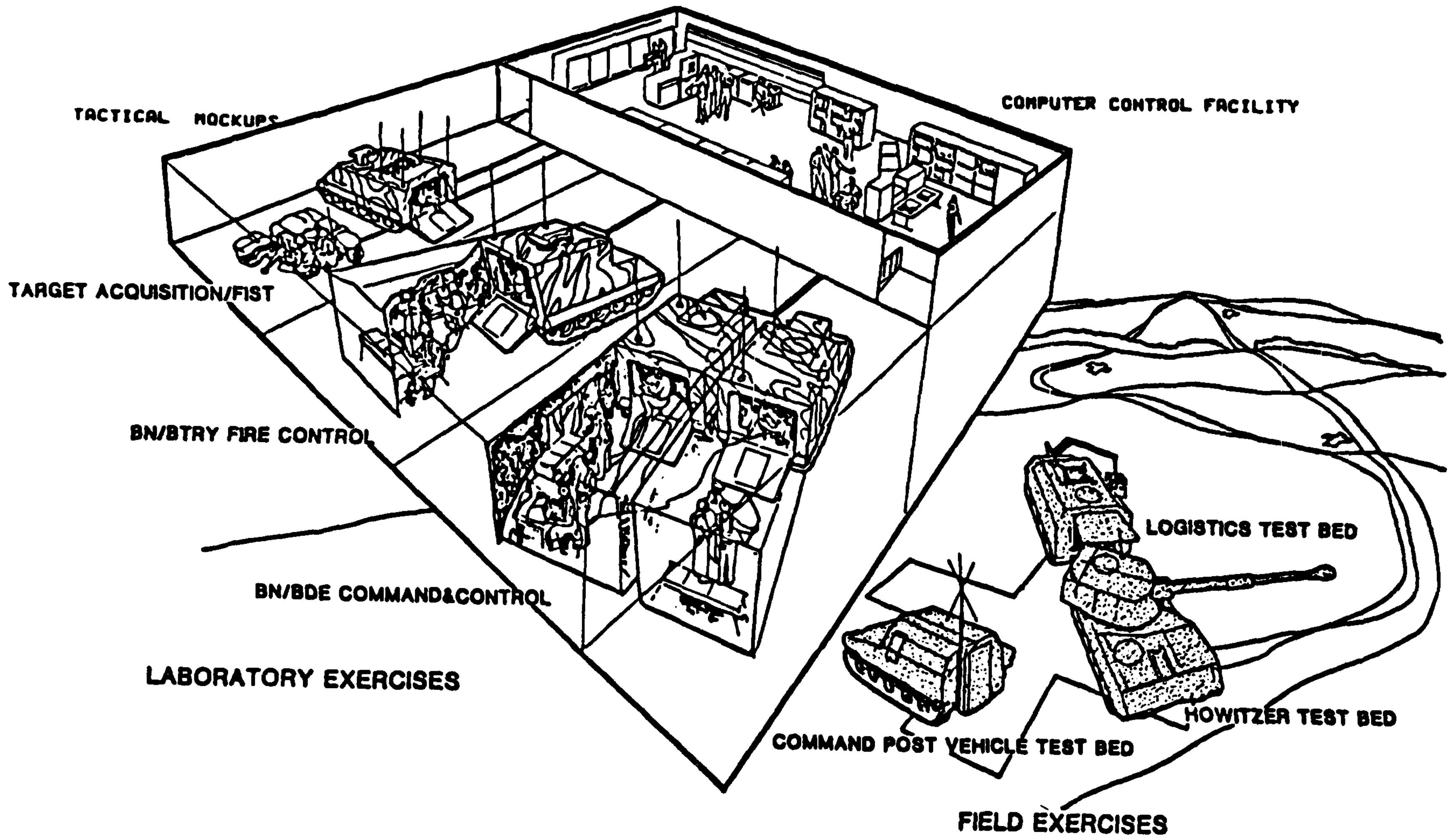

Figure 2. Command Post Exercise Research Facility.

3. To determine if message intensity and degraded communication have a combined effect on fire support coordination.

B. Measures of Performance

A measure of performance (MOP) is a response that is used to quantify the effects of the factors to be evaluated. Because all of our objectives investigated the effect on fire support coordination, the measures of performance were the same for all three objectives. The following measures of performance were computed for each two hour cell of the test:

1. Number of messages serviced by the FIST HQ. This number provides information on the message traffic at the FIST HQ under the different conditions and can be translated into net usage.

2. Frequency count by number of transmissions for messages acknowledged. The FIST DMD has a one character field for try number that cycles modulo 4 (i.e., 0,1,2,3,0,1,2,3,0,...). It was noticed in HELBAT 8 data, that more than four transmissions were sometimes necessary to get an acknowledgement back on a message. TACFIRE uses the try number in the FIST DMD message to determine what authenticator to select for comparison to the DMD message. Therefore, if the number of transmissions exceeds four, the FIST DMD displays a message to the operator to contact his destination by voice to synchronize authenticator codes. This voice-digital contention then causes more problems for a net that is already experiencing communications problems.

3. Frequency count of the number of receptions of a given message at the FIST HQ. Given that a message is transmitted more than once, the message can also be received more than once. Many times a message is sent and received, but the acknowledgement is deleted by communication degradation. The message is then retransmitted and perhaps received again.

4. Service time distribution, where service time is defined to be the time required for the FIST HQ to service a message starting from the time the acknowledgement (ACK) is sent from the FIST DMD acknowledging receipt of a message to the time the response message is first transmitted. This measure includes the time a message spends in the FIST DMD message queue plus the processing and decision time of the FIST HQ.

5. Manual transmission time distribution, where manual transmission time is defined to be the time from first transmission of the response message by the operator to the time an acknowledgement is received for that message. The FIST HQ have completed the decision making at this point, but must continue to send the message until an acknowledgement is received. In degraded communications this time may not be inconsequential. Also, the FIST HQ cannot process other messages while transmitting manually.

6. Number of fire missions completed/number of fire missions initiated. The FIST HQ was given two hours and ten minutes to complete two hours of scenario. A complete fire mission, by definition, is a call for fire (FR GRID), a message-to-observer (MTO), at least one SHOT and an end-of-mission (EOM).

7. Number of fire missions completed/number of fire missions expected. The number of fire missions expected is the number of fire missions in the scenario database. This was to measure if the FIST HQ could complete all fire missions in the two-hour scenario database within the two hours and ten minutes allotted.

C. Scope

The FIST HQ was a four-man team consisting of:

1. the fire support team chief

2. the fire support sergeant

3. two radio telephone operator/drivers.

The FIST chief was available to the FIST HQ for initial supervision only. As per typical operating procedures, the FIST chief may be absent for extended periods of time (hypothetically accompanying the company commander).

The FIST HQ was task-loaded by software interactively simulating three platoon-level forward observers. The software FOSCE (Forward Observer SCEnario) used tactical scenarios developed by Mr. Arthur Long of the US Army Field Artillery Board. This scenario or input database is detailed in Section III-D, "Input Database."

The FIST HQ had direct access to fire support from a company-level mortar platoon fire direction center (FDC) and a generic field artillery fire direction center. All FDC operations were simulated interactively by software. The FIST HQ determined the proper action (based on the FIST chief's guidance and training) for each fire request: either to deny the request, service the request with mortars or forward the request. Fire support was unlimited, that is, not constrained by ammunition resupply; this was not to be a study factor for this experiment.

All members of the FIST HQ crew were trained in the operation of the FIST DMD to give the FIST chief flexibility in managing his team.

D. Limitations

1. All forward observer addresses were placed in the review mode in the FIST DMD subscriber table.

2. After deciding a fire request should be handled either by the mortars or forwarded to the FDC, the fire mission was forwarded in the automatic mission mode. That is, all subsequent messages for that fire mission were automatically routed through the FIST DMD. Operator intervention was needed only if a message did not get acknowledged in four transmissions. He was then notified that the message did not get ACKed; the message was placed in his message queue and transmitted manually.

3. No FIST HQ initiated missions were included.

4. No tactical chores were performed, e.g., guard duty, close station march order, emplacement, etc.

5. All communications were digital; the simulators could not respond to voice communications.

E. Test Configuration

Figure 3 shows the nodes that were played in the first military player test: (1) the FIST HQ equipped with the FIST DMD in the mock-up vehicle interacting through Ether, the intracomputer communications network, with the three forward observer scenario programs, (2) the mortar fire direction simulator and battalion fire direction simulator. Figure 4 shows how these components were netted.

III. RESOURCE REQUIREMENTS

A. Software

ACE software permitted real-time fire support command and control functions to be exercised in a controlled laboratory environment. The software is written in the C programming language and is designed to run under the 4.1bsd (Berkeley) UNIX operating system.

The two simulator programs, FOSCE (Forward Observer SCEnario) and FDS/MFDS (Fire Direction Simulator/Mortar FDS) interactively simulated both tactical equipment and its human operators. FOSCE mimicked the actions of the platoon forward observers that work for the FIST HQ while the FDS programs simulated generic artillery battalion and mortar fire direction centers, respectively, executing fire missions. It had to be determined exactly how the simulators should react to the many different events that could occur during the scenario. This required group participation and each possible event had to be discussed. Many different factors were taken into consideration such as tactical realism, physical constraints, and the test design. Most of the events could be handled in more than one way and a decision had to be made (that was sometimes arbitrary) as to how the simulator should react. This problem was compounded by the introduction of degraded communications. Even a simple adjust fire mission includes over 30 messages that could be randomly deleted during degraded communications operations, and the simulators had to adjust to react to this (note Figure 5).

Some operations that are normally handled via voice with TACFIRE had to be implemented using digital means for the simulators. For example, fire missions from FOSCE could be rejected or ended by sending a freetext message "MISSION REJECTED." If a target number had been assigned, FOSCE would send an End Of Mission and Surveillance (ES) message and then wait for the next mission. An ES message would cause the FDS or MFDS to end a mission already in progress.

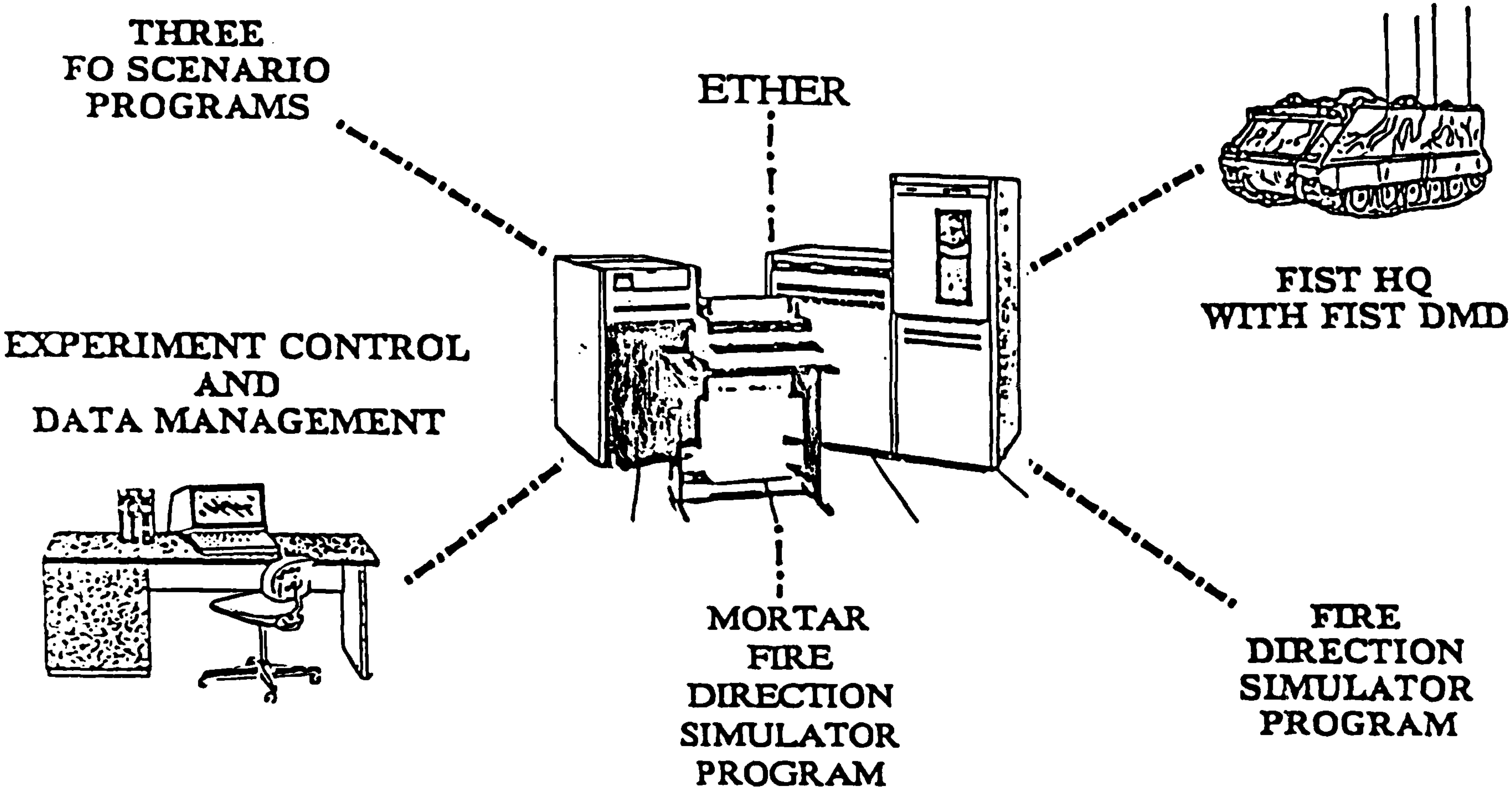

Figure 3. FIST Headquarters Experiment.

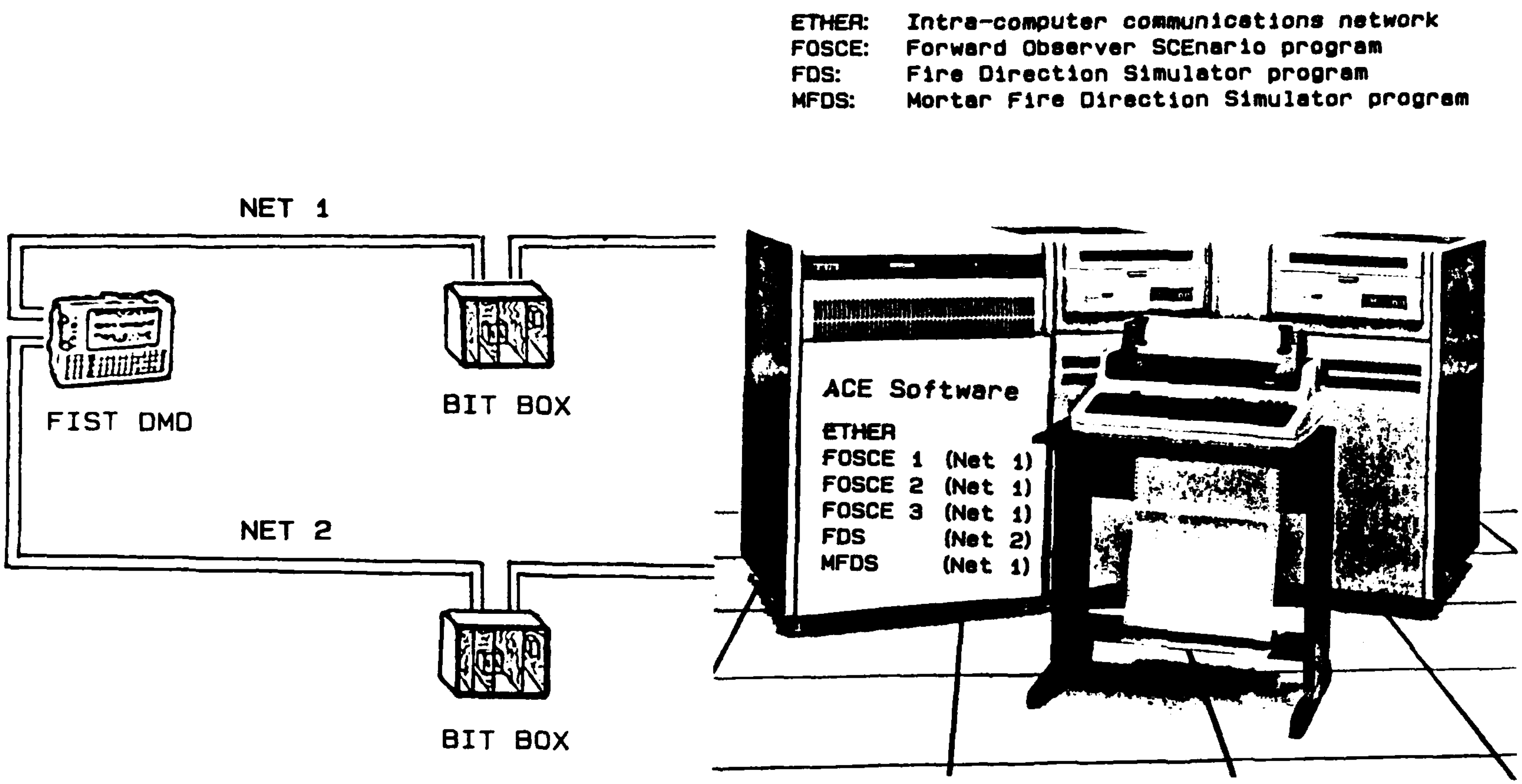

Figure 4. Test Configuration.

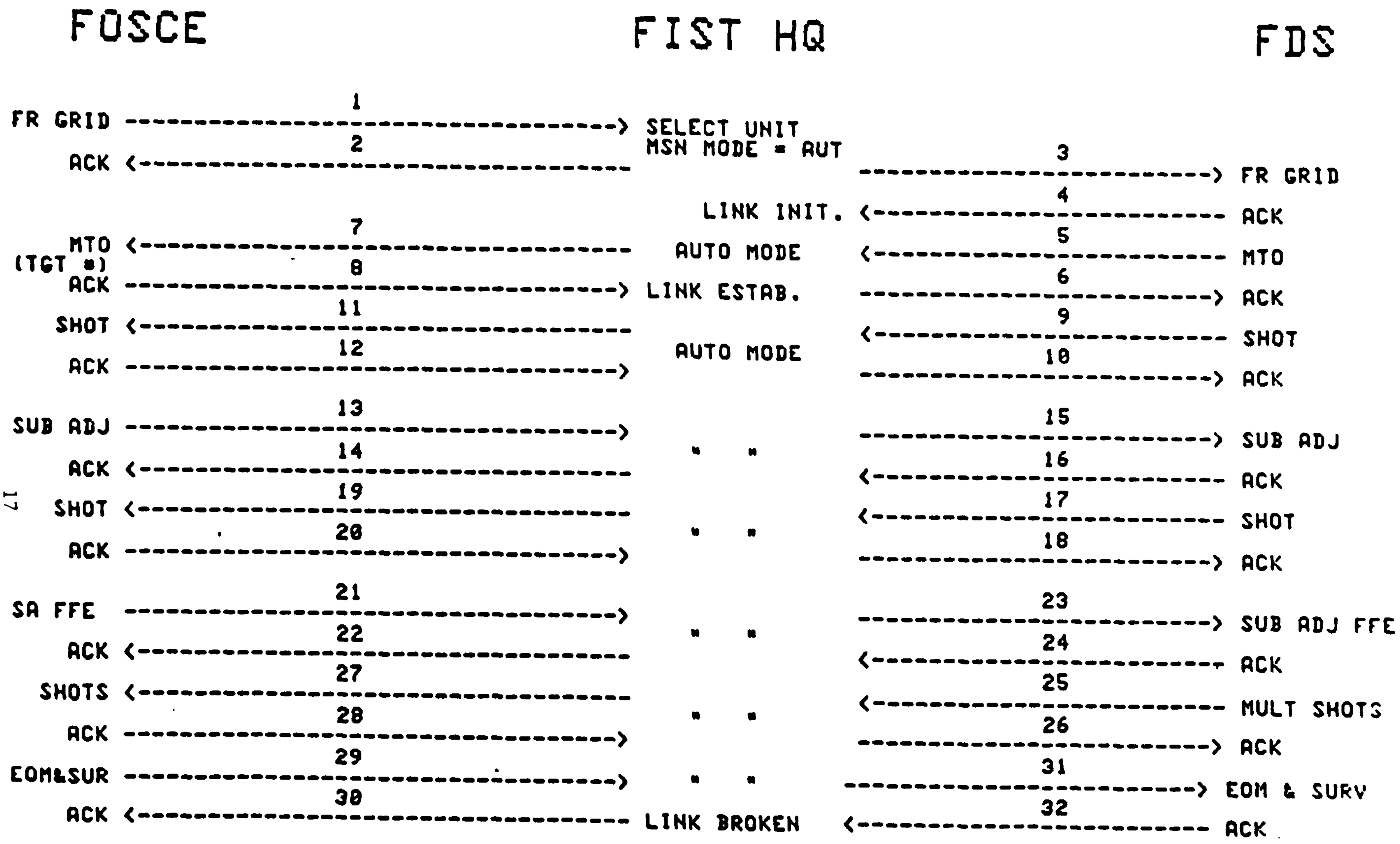

Figure 5. Simple Adjust Fire Mission.

Despite the capability built into the simulators to handle degraded communications, "deadlock" situations still occurred. This would happen when a message that was lost from one simulator was required by another simulator to continue processing. A common example of this occurred when a Subsequent Adjust message from FOSCE, which was to be relayed automatically to the FDS by the FIST DMD, was lost during the relay. Although the FIST DMD warned the operator when such a situation existed, the warning was sometimes missed, inadvertently deleted, or more urgent problems forced a delay in reacting to the warning and it was forgotten. Hence, FOSCE was content because the message it sent was acknowledged by the FIST DMD; FOSCE was waiting for a SHOT message. But the Subsequent Adjust message for which the FDS was waiting never arrived; both simulators were waiting for something from the other. It was noted by a Field Artillery School instructor that this situation is not uncommon in the real world. To solve this problem, the simulators had to be able to respond to queries from the FIST HQ. Freetext fire mission "status" messages were defined so that the FIST HQ could inquire about the current status of a fire mission by referencing either a Target Number or an Observer Identification number and DMD mission buffer. These inquiries could be sent to either the FOSCE or FDS programs, and based upon the response, the FIST HQ could take action to fix the deadlock situation or end the mission.

Special messages were developed to allow the simulators to add information to the database. These messages were sent to reserved addresses so that they could be easily identified in the database later. The simulators did not expect acknowledgement for these messages. Some of these messages were displayed by ADIS for the controllers to identify special events, such as a simulator not receiving an acknowledgement after four transmission attempts, or the reception of a duplicate fire mission by the FDS (i.e., same as one already in progress). Other messages were simply entered into the database for use during data reduction. These were typically messages that announced that a particular simulator was beginning or ending a fire mission. They identified the time that the simulators believed a fire mission started or ended regardless of the actions of the live players. These messages were used by the data reduction software to identify when events actually began or ended despite the confusion caused by the communications degradation.

The capability to start or end a cell anywhere within that cell was implemented to allow the controller to restart a cell if a computer hardware malfunction was encountered, thus eliminating the need to redo a complete cell. This capability was utilized only two or three times during the entire experiment but it did save several hours of test time.

The major components of the ACE software are described in the following sections.

1. <u>Ether.</u> Ether is a single program which functions as an intra-computer communications network. Computer ports are assigned to communication nets. Ether accepts a message from a port and transmits it to all other ports on the assigned net. Message collisions are prevented by separately buffering each message within Ether. Although Ether prevents collisions between messages, the TACFIRE digital network is a half-duplex system; only one player at a time can transmit a message without a collision. Thus, messages between the FIST DMD and the Bit Boxes had a small probability of collision. This non-zero probability was observed and measured during the experiment.

Each net is assigned a probability of message loss which ranges from zero to one. If the probability of message loss is zero, the net is an ideal net, and all messages are sent to each port on the net. If the probability of message loss is greater than zero, a uniform random number generator is used to decide whether or not a message is lost. Lost messages are not transmitted to any port on the net. Acknowledgements (ACKs) are treated the same as any other message.

Ether maintains a log file of each message which it receives. In addition to the raw message, the log contains the times (Julian day, hour, minute, second) for the start of the message, the end of the preamble and the end of the message.

2. ACE Display and Information System (ADIS). A real time display program, named ADIS (ACE Display and Information System), allowed the controllers to see all the messages as they passed between real and simulated players. The display, along with a chronological listing of the scenario, was used by the controllers to track the progress in the test cells. It proved essential in identifying and collecting information on unusual events, which normally developed quickly and were hard to trace. This was even more important during the extensive debugging phase of the experiment. The Field Artillery School instructor also found it helpful in following the progress of the students during the training phase.

A camera and microphone were placed in the FIST vehicle mock-up to record the face of the FIST DMD and the crew's conversations. These were simultaneously recorded with the ADIS Display so that a complete picture could be obtained at a later time to identify specific parts of the scenario that caused problems and the events that led up to them. When the ADIS display was combined with the actual actions of the crew, it presented a comprehensive picture of how the test group (FIST) interacted with the entire system.

ADIS utilizes a CRT (cathode ray tube) terminal to display in real time the messages being transmitted through Ether. The terminal screen is divided into eight columns which are labeled for the players (see Figure 6). Each message is displayed as two lines in both the sender's and receiver's columns. The message first appears in the sender's column. The first line contains the message type and target number if it has been assigned. The second character in the second line is a "^", indicating "sender," and the time sent is given. The message will then appear in the "receiver's" column. The first line is the same as in the "sender's"; the second character in the second line gives the address of the "sender," and the time received is displayed. When the acknowledgement is sent by the "receiver," an "*" is displayed as the first character in the second line of the "receiver," and when the acknowledgement is received by the "sender," an "*" is displayed as the first character in the second line of the "sender" message. If the message is deleted by Ether, "MSG LOST" appears in the receiver's column. Below the columns, the last message sent is fully depicted, time tagged, and deciphered. At the bottom of the screen, the time from the start of the run is displayed.

3. Forward Observer Scenario (FOSCE). The forward observer scenario program reads a database of forward observer (FO) messages and transmits the messages as if they were being generated by a real FO with a DMD. Each message is time-tagged in the database and sent by FOSCE at the appropriate time. FOSCE waits 10 seconds for an ACK; if one is not received, it retransmits the message. Three retransmissions (for a total of four) occur before the program gives up. If no ACK is received after four transmissions of a fire request, FOSCE waits four

```
----------------------------------------------------------------------------
FO       1|FO       2|FO       3|FIST     F|FDS     V|MFDS    B|       a|
----------------------------------------------------------------------------
FR GRID  |          |         |FR GRID  |         |         |         |
*^  10:19|          |         |*1  10:21|         |         |         |
         |          |         |         |         |         |         |
         |          |         |FR GRID  |         |FR GRID  |         |
         |          |         |*^  11:06|         |*F  11:08|         |
         |          |         |         |         |         |         |
         |          |         |MO AF3700|         |MO AF3700|         |
         |          |         |*B  11:43|         |*^  11:41|         |
         |          |         |         |         |         |         |
MSG LOST |          |         |MO AF3700|         |         |         |
 F       |          |         | ^  11:45|         |         |         |
         |          |         |         |         |         |         |
MO AF3700|          |         |MO AF3700|         |         |         |
*F  11:54|          |         |*^  11:52|         |         |         |
         |          |         |         |         |         |         |
----------------------------------------------------------------------------
                          *****retry 1*****
transmitter -> receiver :        -       -       -       F -> 1
message type            :        -       -       -         MTO
target number           :        -       -       -       AF3700
transmit /107:00:11:52\   end preamble /107:00:11:53\   end msg /107:00:11:53\
msg            : 10AADFS10603700  30 1  10401000111 008400100


                          /000:00:11:54\
```

Figure 6. Sample ACE Display (ADIS).

minutes (hopefully long enough to resynchronize authenticator codes with TACFIRE by voice) and then recycles the call-for-fire. FOSCE, after receiving an ACK on a request for fire, waits 10 minutes for a message-to-observer (MTO) message. If one is not received, it resends the request for fire. After receipt of the MTO, FOSCE waits up to 5 minutes for a SHOT message. Once the SHOT message is received, FOSCE waits at least 90 seconds before transmitting subsequent adjust (SA) messages. Because no voice communication was allowed, FOSCE was made smart enough to respond to freetext messages asking for the status of a particular fire mission by target number or for the status of FOSCE itself, that is, active or not active.

4. Fire Direction Simulator (FDS). The fire direction simulator consists of four programs which perform a limited number of TACFIRE/BCS functions. FDS accepts fire request messages, prioritizes them, assigns target numbers and generates MTO and SHOT messages. Times between receipt of fire requests and transmission of MTO and SHOT messages vary due to the computer workload and an internal random number generator. If the computer is not overloaded, the time between the fire request and the MTO randomly varies between 15 and 45 seconds, and the time between the SA and the SHOT varies between 20 and 40 seconds. The number of simultaneous missions which the FDS will process may be specified. If the number of missions exceeds the maximum, the FDS will process missions based on mission priority. During this experiment, the FDS could handle up to 10 missions simultaneously, which by intent was not a limitation on the system. The FDS could be queried by the FIST HQ as to the status of a particular fire mission by target number or by observer identification number and mission buffer.

5. Mortar Fire Direction Simulator (MFDS). The mortar FDS simulates the digital communication of the company mortar FDC. It is a special version of the FDS program which will only accept one fire mission at a time.

6. Bit Box Program (BBP). The Bit Box interface program accepts messages from Ether and transmits them to a computer port which is connected to a Bit Box. The program also reads messages from the computer port and transmits them to Ether.

B. Hardware

1. Two Bit Boxes. Bit Boxes are microprocessor-based MODEMs which enable TACFIRE hardware to interface with commercial computers. Bit Boxes accept TACFIRE messages from wire line or radio, perform error correction and convert the messages to RS232 ASCII characters, which commercial computers can accept. They also accept messages from the computer, add the error correction bits, time disperse the messages and transmit them over wire line or radio in TACFIRE format (FSK).

2. FIST DMD. The FIST digital message device that was used in the experiment was one of four experimental design models (EDM #2) that are in existence. It was a prototype model, and not a production model.

3. VAX 11/750 Computer. The VAX 11/750 computer was dedicated to running the experiment and had no other processes running during the test. The operating system was the 4.1bsd (Berkeley) UNIX.

C. Training

Test participants were collectively trained at the Human Engineering Laboratory in the operation of the FIST DMD by CPT Gahagan, an instructor from the Gunnery Department of the US Army Field Artillery School. The Human Engineering Laboratory provided training equipment for the students. The test participants were trained Fire Support Teams (MOS 13F) from the 82nd Airborne Division, Ft. Bragg.

The FIST could continue fire support coordination operations through 30 percent communications degradation once trained to do so. A key lesson they learned was to use a "wait and see" technique after failing to get an ACK to a message after four tries. Usually it is the ACK, rather than the message, that is lost. (This situation could become quite common when a mobile observer with a low power radio is communicating with a station that has a good antenna and a high powered radio, for example, an FDC.) Hence, by waiting a few minutes the expected response message was received even though the ACK never was. The FIST also learned to use the "status" messages to find and fix deadlock situations thus resorting to digital, rather than voice, means to correct problems. However, they still depended upon paper and pencil to keep track of what target numbers were active along with the progress of each mission.

D. Input Database

The tactical scenario database contained fire support control messages for a limited scenario of a mechanized infantry battalion of an armored division. The SCORES, Europe III, Sequence 2A was used to generate fire missions expected to be fired by a field artillery battalion in sustained combat operation. The battalion is constrained by ammunition resupply under normal operations; however, it was decided that ammunition resupply should not be a limiting condition in this test. The entire scenario was played in retrograde mode.

Scenario definition is still very subjective. For this experiment a scenario was defined to be a time ordered list of digital messages, and in this case, messages that would be received by the FIST HQ from its platoon forward observers (FO) using TACFIRE Digital Message Devices (DMD). It was surprising that no definition of "intensity" could be found that was given in terms of number of fire missions (FM) or messages per hour. Hence, a "reasonable" guess had to be made: Low Intensity - 1 Fire Mission per FO per hour, Medium - 2 FM/FO/hour, and high - 3 FM/FO/hour. The number of Artillery Target Intelligence (ATI) messages was varied inversely from the FMs, and an Immediate Smoke mission was added to each medium and high intensity cell (each cell was 2 hours long).

Because cells of the same intensity were to be compared, several other criteria were imposed on the scenario to insure that task loading on the FIST HQ didn't vary significantly between cells of the same intensity. The ratio of Fire For Effect (FFE) to Adjust Fire (AF) missions was chosen as 2:1 (as per Ft. Sill's direction), the number of adjustments in each AF mission was chosen as three, and one fire mission in each 2-hour cell was designated as urgent rather than normal priority. After the scenario was received, it was realized that the time interval between fire missions was also a significant factor that influences the loading on the FIST HQ. Since this timing wasn't specified in the scenario definition, all the fire mission time-tags were changed manually so that the intervals between the fire missions were the same for each cell of the same intensity. This was a time consuming procedure (60 man-hours). Some factors that were not analyzed in the first CPX experiment (but perhaps should have been) were the ranges to the targets, the target descriptions, and how often or which targets were in range of the available fire support assets. These factors would certainly affect the FIST HQ perception of the threat and perhaps the urgency attached to tasks, both of which might influence the results of tests like this one.

The database consisted of 36 two-hour cells of messages: 12 two-hour cells of low intensity, 12 two-hour cells of medium intensity and 12 two-hour cells of high intensity. Intensity is defined by the number and type of initiating messages per two-hour cell as given in Figure 7, and the message stream that follows each initiating message as given in Figure 8. It can be seen that intensity is a function of the number of initiating messages and their subsequent messages. The 36 two-hour cells of data were arranged such that all permutations of the three intensities (L-M-H) appeared twice. Ninety percent of the fire missions had normal priority, and the other ten percent had urgent priority.

The process of verifying that the large, 144-hour scenario contained what was requested could only be achieved practicably through automatic means. The scenario was delivered on computer tape and loaded into the BRL computer(s) where it could be manipulated with the many standard software packages included with the UNIX Operating System. Several other programs were written to examine the database and display information concerning the factors listed above. (Most of these programs were written in a convenient pattern scanning and processing language named AWK.)

The messages in the scenario had to be converted from a "pseudo TACFIRE" format to the "Fixed Format" used by DMDs. The program written to do this was "table driven." This type of program is relatively quick to write and fast in execution, however, it is intolerant to errors; therefore, any deviation from the expected input format produced an error. There were many format errors in the input database (e.g., the abbreviation for a target disposition, DISPO, was often missing the "I," DSPO) that required manual alterations, an unexpected time consuming task on the large database.

IV. DATA COLLECTION

A. Experimental Design

1. Factors. The two factors that were tested in this experiment were message intensity and communication degradation. Three levels of message intensity were tested with each of three levels of communication degradation giving nine test combinations. The levels of each factor are abbreviated as follows:

FACTORS

1) INTENSITY (per two hour block)

MESSAGE TYPE	LEVELS Low	Medium	High
Fire Mission 1, Fire For Effect	4	8	12
Fire Mission 2, Adjust Fire	2	4	6
Fire Mission 3, Immediate Smoke	0	1	1
Artillery Target Intelligence	18	12	6

2) COMMUNICATION DEGRADATION

00% Message Loss
15% Message Loss
30% Message Loss

Figure 7. Factors for FIST Experiment.

INTENSITY			
	LEVELS		
MESSAGE SEQUENCE	L	M	H
1) Artillery Target Intelligence ATI FO→FIST→FDC	18	12	6
2) Fire Mission, Fire for Effect FR GRID FO→FIST→FDS MTO FO←FIST←FDS SHOT FO←FIST←FDS EOM FO→FIST→FDS	4	8	12
3) Fire Mission, Adjust Fire FR GRID FO→FIST→FDS MTO FO←FIST←FDS SHOT FO←FIST←FDS SA(1) FO→FIST→FDS SHOT FO←FIST←FDS SA(2) FO→FIST→FDS SHOT FO←FIST←FDS SA(3) FO→FIST→FDS SHOT FO←FIST←FDS EOM FO→FIST→FDS	2	4	6
4) Fire Mission, Immed. Smoke Same as Adjust Fire Mission	0	1	1

Figure 8. Subsequent Message Flow (w/o ACKs) by Message Type.

Message Intensity

L = low

M = medium

H = high

Communications Degradation

0 = 0% degradation

1 = 15% degradation

2 = 30% degradation

2. <u>Design Matrix.</u> It was decided that the shortest reasonable time to test any one of the nine treatment combinations was two hours. Since the testing of all nine treatment combinations required a minimum of 18 hours, which realistically could not be completed in one day, a randomized incomplete block design was constructed so that the day-to-day variability would not influence the results. The nine treatment combinations were divided into blocks of three, and the three blocks were run over a three day period. The assignment of the treatment combinations into blocks was based on a confounding scheme. This scheme assured that the effects of message intensity (I), communication degradation (C) and the interaction of these two factors (I x C) on a FIST HQ ability to perform fire-support coordination could be measured. Because time constraints permitted only two replications, part of the precision of the estimate of the interaction was sacrificed (i.e., blocks within replicate 1 were confounded with the linear component of the I x C interaction and blocks within replicate 2 were confounded with the quadratic component of the I x C interaction). Randomization of treatment combinations within blocks and blocks within days was performed.

The experiment was repeated for four FIST teams, so that team-to-team variability was included. In addition, software changes were implemented between teams 2 and 3 as a result of information from a pilot test. One significant change was to have the FDS send one SHOT message per call-for-fire rather than one SHOT message per volley. Capability for status requests was implemented in the FDS at this time also. Because of these changes, software was made a factor in the experiment so that the variability due to the software changes could be detected.

The design matrix is shown in Figure 9. The FIST teams were tested sequentially, one at a time, for six days. The six days are shown in the design matrix and the tests were run in the order given within each day.

DESIGN MATRIX						
FIST	REP1			REP2		
TEAM	DAY1	DAY2	DAY3	DAY4	DAY5	DAY6
TEAM ONE	L2 M1 H0	M0 H2 L1	L0 H1 M2	M0 H1 L2	L0 M1 H2	H0 L1 M2
TEAM TWO	H1 L0 M2	H2 M0 L1	L2 H0 M1	M1 L0 H2	M2 H0 L1	H1 M0 L2
TEAM THREE	M2 H1 L0	H2 M0 L1	M1 L2 H0	L0 M1 H2	H1 M0 L2	M2 H0 L1
TEAM FOUR	H2 M0 L1	M1 L2 H0	M2 H1 L0	H1 M0 L2	L1 H0 M2	L0 M1 H2

INTENSITY	COMMUNICATION DEGRADATION
L— LOW	0— 00% DEGRADATION
M— MEDIUM	1— 15% DEGRADATION
H— HIGH	2— 30% DEGRADATION

Figure 9. Design Matrix for Experiment.

V. DATA ANALYSIS

A. Statistical Analysis

Reducing 45,000 messages recorded in this 72 two-hour cell experiment into meaningful information was not a simple task. The reaction of the FIST DMD operators to degraded communications often produced results that were unexpected or difficult to trace. As mentioned earlier, the slight delay in acknowledgement messages (ACK) coupled with the heavy message traffic often made it difficult to match ACKs to messages after the fact. Human analysis was still required to retrieve many results; however, many of the standard programs available with the UNIX Operating System were invaluable to assist in this work.

1. Effect of Factors on Message Traffic. The total number of messages generated for each experimental condition over a two-hour cell was used to evaluate and validate the effect that the different factors and their interactions had on message traffic. Based on the way intensity and communication degradation were defined in planning this experiment, we expected these two factors to have a significant effect on message traffic. An increase in intensity level resulted in an increase in the number of messages generated. Similarly, an increase in communication degradation resulted in an increase in the number of messages it took to complete a fire mission or to forward an artillery target intelligence message. To some this may seem counter intuitive; however, in degraded communications, some messages were being sent but not received, and this resulted in retransmissions which increased message traffic. The other factors specified in the design, including the two different Fire Direction Simulator software programs, were also included in this analysis.

The number of messages observed in each test cell are shown in Figure 10. An analysis of variance was performed on this data with all replicate interaction terms pooled for the error term. A second analysis of variance procedure was then performed with additional interaction terms found not to be significant also being pooled with error. The ANOVA table for the final reduced model is shown in Table 1. It should be noted that since block was confounded with components of the intensity-degradation interaction, it was not meaningful to test any term in the model containing block. A double star next to the F-statistic indicates that the factor is significant. Based on the calculated F-values, intensity, degradation, intensity-degradation interaction, software, and intensity-software interaction, were found to have a significant effect on the message traffic.

The effect that intensity, degradation and their interaction have on message traffic is summarized in Table 2. Table 2 gives the average number of messages per two-hour cell, μ, and the number of cells in the average, N, for the given factors and their marginal effects (averages over the rows and columns). Looking at the average number of messages generated for each level of intensity presented in the right-hand column of Table 2, one sees that there was a significant increase from 361.46 to 882.50 as intensity increased. Similarly, an increase in communication degradation increased the average message traffic flow from 462.13 to 798.58. In addition, in comparing the mean change between the different levels of communication degradation for each level of intensity, a positive interaction effect can be noted. There was an increase in the mean of about 200 messages between 0 percent and 30 percent degradation for

Software	Intensity	Fist Team	Communication Degradation 00 RepI	00 RepII	15 RepI	15 RepII	30 RepI	30 RepII	Total
S1	L	Team1	293	279	410	335	508	494	4638
		Team2	285	279	351	413	516	475	
	M	Team1	512	466	739	723	750	771	8491
		Team2	552	564	781	649	1132	852	
	H	Team1	811	700	873	1099	1276	1293	12239
		Team2	778	808	990	1072	1216	1323	
S2	L	Team3	288	230	316	286	508	438	4037
		Team4	243	238	314	390	386	400	
	M	Team3	393	396	576	506	722	742	6672
		Team4	409	396	556	558	730	688	
	H	Team3	518	544	684	722	995	966	8941
		Team4	563	546	726	692	881	1104	
TOTAL			11091		14761		19166		45018

Figure 10. Number of Messages Observed in Design Matrix.

TABLE 1

ANALYSIS OF VARIANCE (EFFECT ON MESSAGE TRAFFIC)

ANALYSIS OF VARIANCE (ANOVA)				
SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F RATIO
Replication	1	288.00	288.00	*
Software	1	454104.50	454104.50	128.19**
Block within Rep	4	67391.34	16847.54	
Software X Block within Rep	4	8701.11	2175.28	
Team within Soft X Block within Rep	8	40628.52	5078.56	
Intensity	2	3259353.58	1629676.79	460.04**
Software X Intensity	2	152010.75	76005.37	21.46**
Degradation	2	1362202.08	681101.04	192.27**
Intensity X Degradation	4	103933.83	25983.41	7.33**
Pooled Error	43	152325.79	3542.46	
Total	71	5600939.55		

TABLE 2. Number of Cells in the Average (N) and Average Number of Messages Per Two Hour Cell (μ)

Intensity	Communication Degradation (%) 00	15	30	
LOW	8 266.88	8 351.88	8 465.63	24 361.46
MEDIUM	8 461.00	8 636.00	8 798.38	24 631.79
HIGH	8 658.50	8 857.25	8 1131.75	24 882.50
	24 462.13	24 615.04	24 798.58	N μ

low intensity compared to an increase of over 300 messages for medium and 500 messages for high intensity.

The effect that software and the software-intensity interaction had on message traffic is summerized in Table 3. The average number of messages generated per two-hour block for the original FDS software program was 704.67 compared to 545.83 for the modified program. The software was changed to produce a shot message for every call for fire instead of every volley which is a more realistic representation of how TACFIRE/BCS functions. Therefore, one would expect the average message flow to be less for software 2 than 1. Also, one would expect a greater change between low, medium and high intensity for software 1 than 2. From Table 3, the difference between means for low and high intensity for software 1 is over 600 messages compared to a difference of slightly over 400 for the modified software. To obtain a realistic description of the effect that message intensity and communication degradation had on network message traffic flow and on the Fire Support Teams' ability to perform effective fire support coordination, the analysis from this stage on was based on the second half of the experiment using the modified software.

TABLE 3. Number of Two Hour Cells in the Average (N) and Average Number of Messages Per Two Hour Cell (μ)

Software	Intensity Low	Medium	High	
1	12 386.5	12 707.58	12 1019.02	36 704.67
2	12 336.42	12 556.00	12 745.08	36 545.83
	24 361.46	24 631.79	24 882.50	N μ

The number of messages per unit time can be translated into net usage. Net usage is defined to be the percent of time a net is occupied by message transmissions. Message traffic during this test was handled by two nets. Net 1 represented the company fire control net and consisted of the links between the three forward observer simulators, the FIST HQ and the company mortar fire direction simulator. Net 2 was the fire direction (FD) net and connected the Fire Support Team and the battalion fire direction center simulator (FDS). In a direct support artillery battalion, there are three fire direction nets, one for each battery, that each link TACFIRE (bn FDC), a BCS (battery FDC), a VFMED (bn FSE) and three FIST DMDs (FIST HQ). The fire direction net was not fully loaded during this experiment; only one Fire Support Team exercised the FDS. Also, the FIST HQ have the capability to monitor two other nets, the company command net and the battalion mortar fire direction net which were not used during the test.

The time a net is busy is a function of the number of messages passing through the network, the lengths of the messages and the appropriate preamble times as imposed by the Bit Box, the DMD, or the FDS software. FOSCE had no preamble set during the test.

Acknowledgements and 48 character DMD fixed format messages were used to compute net usage. Neither of the message types were compressed at any time during the test. Figure 11 illustrates the format of a DMD message transmission which always includes a preamble, synch characters, and the message. Preambles, which take a certain amount of time to be transmitted, allow the transmitting and receiving radios to reach operating conditions and help synchronize the DMD receiving devices. The synch characters serve as a start of message indicator and tell whether or not the incoming message is encrypted. The message is comprised of three parts: the header, which identifies the message transmitter and assures that the message is valid, the body of the message, and the tail, indicating the end of message transmission and which, by TACFIRE protocol, must contain at least 4 EOTs. All messages, including acknowledgements, were passed through a Bit Box which imposed a preamble time of 0.1 seconds. In addition, the DMD and the FDS software each imposed their own preamble of 1.0 seconds when transmitting.

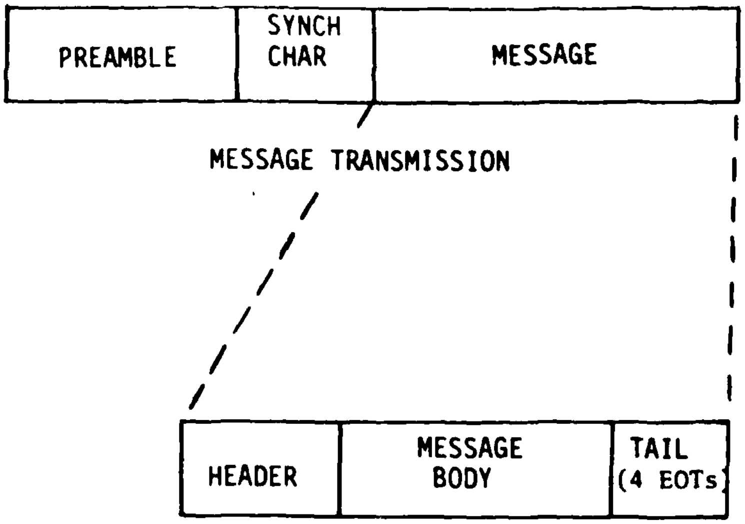

Figure 11. Message Transmission Format.

The 32-bit synch characterization is the same for acknowledgements and other message types; however, the average length of the message itself varies between the two. The message length of an acknowledgement is one block long. A block consists of 16 characters, and a character is 12 bits, therefore, the message length of an acknowledgement is 192 bits. Including the synch characters, the total number of message transmission bits for acknowledgements becomes 224. All 48 character DMD messages are three blocks long resulting in a message length of 576 bits and a total message transmission length of 608 bits. All message transmissions were sent at a rate of 1200 bits per second.

Net usage was computed by dividing the total message transmission time, including preamble time, on a net by the total net time available. Table 4 gives the average net usage in percent for each intensity-degradation combination and the marginal net usage for each of these factors. It can be seen that although a change in degradation level from 0 to 15 percent increased the average number of messages by 33 percent (from 462 to 615), the increase in net usage was only between one and two percent. Similarly, an increase from 0 to 30 percent

TABLE 4. Net Usage by Percent of Time

Intensity	Net	Communication Degradation			Average Net Usage
		00	15	30	
Low	1	1.6	2.1	3.0	2.2
	2	2.6	3.4	4.3	3.4
Medium	1	2.6	3.8	4.9	3.8
	2	4.0	5.5	7.4	.6
High	1	3.6	4.9	6.9	5.1
	2	5.5	7.0	10.0	7.5
Average Net Usage	1	2.6	3.6	4.9	3.7
	2	4.0	5.3	7.2	5.5

degradation produced an increase of 73 percent (from 462 to 799) in the average number of messages; the net usage increased between 2 and 4 percent. The net usage would increase considerably if the system were fully loaded and voice communication added. The percentages indicate that the actual transmission time for a large number of digital messages is very small and that little reduction in total fire mission time could be gained by decreasing the transmission time of digital messages. However, it is important to note that the FD net (Net 2) usage ranges from 2.6 to 10.0% with only one of the three or four FISTs operating and without the message traffic between TACFIRE, BCS and VFMEDs, which are long variable format messages; therefore, net contention could be a serious problem when the net is fully loaded.

2. Frequency Count by Number of Transmissions of Messages Acknowledged. Theoretically, the number of transmissions it takes for a message to successfully reach its destination and for an acknowledgement to be received by the sender should only be affected by the percent of communication degradation in the communication networks. Given the actual percent degradation, the theoretical distribution of how many times a message is sent before it is acknowledged can be determined for each level of communication degradation. When there is

no communication degradation, all messages should be acknowledged on the first try. In 15 percent degradation the probability that a message gets through and is acknowledged on any try is (1-.15)(1-.15)=.7225. The probability that a message does not get acknowledged on a given try is 1-.7225. Using these probabilities, the probability that a message is acknowledged in a given number of transmissions can be computed. Table 5 gives the distributions of the theoretical probability of getting a message acknowledged in n transmissions for 15 and 30 percent degradation.

TABLE 5. Theoretical Probability That A Message Is Acknowledged In n Transmissions

Number of Transmissions	General Formula	Degradation Level 15%	Degradation Level 30%
1	p	.7225	.4900
2	$p(1-p)$	.2005	.2499
3	$p(1-p)^2$	.0556	.1274
4	$p(1-p)^3$	.0154	.0650
.	.	.	.
.	.	.	.
.	.	.	.
n	$p(1-p)^n$	.	.

Using the theoretical probabilities from above and the total number of messages actually acknowledged under each degradation level, the actual effect of ACE's communication degradation can be checked. Figure 12 shows the distribution of total messages acknowledged by try number in "perfect" communications (0 percent degradation) for software 2. "Perfect" communication was not quite perfect.

Figures 13 and 14 give the same distributions for 15 and 30 percent degradation. Very good agreement was observed, and when tested statistically (See Appendix A), the number of messages acknowledged by number of transmissions was a function of communication degradation only and was not influenced by intensity, team variability or learning.

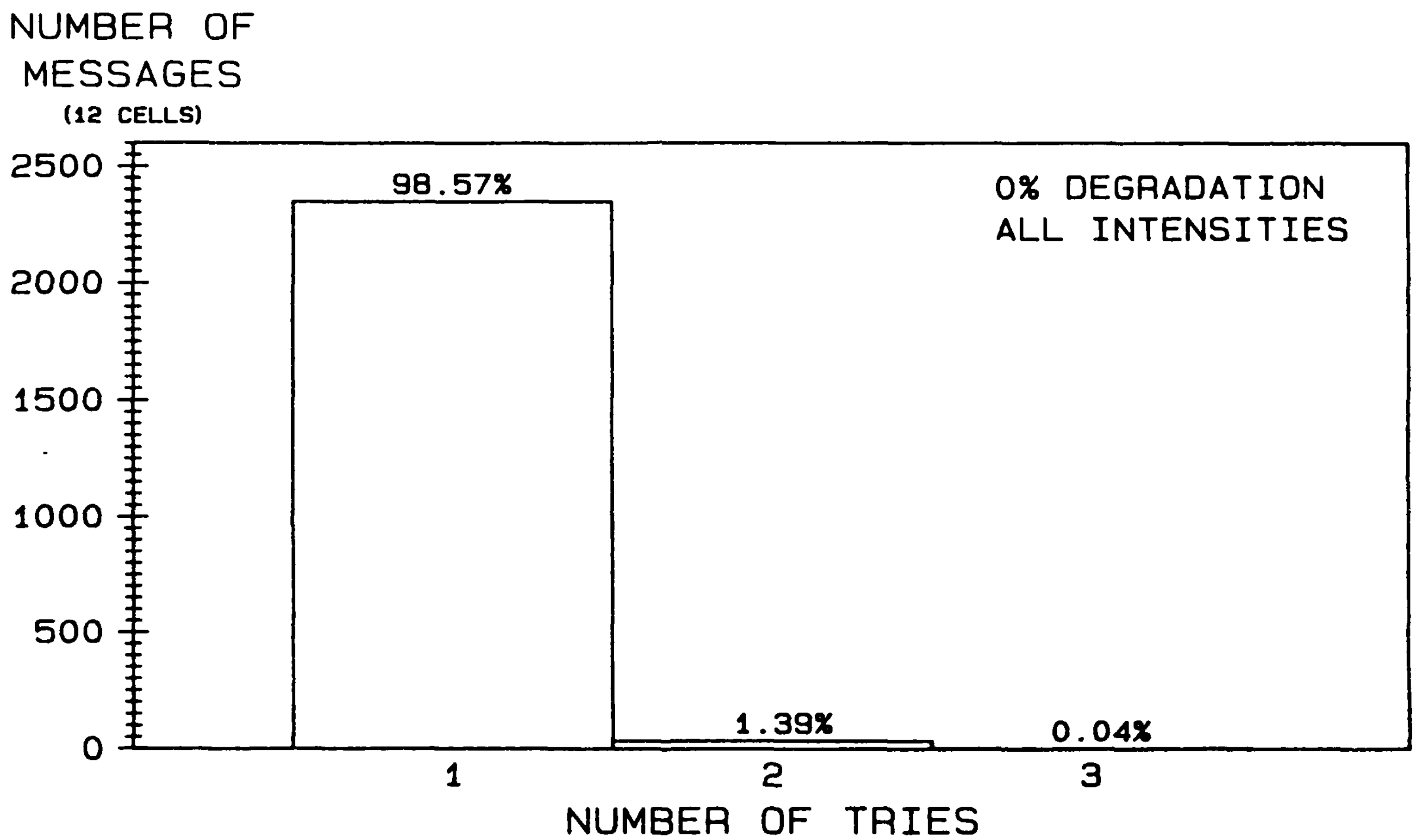

Figure 12. Distribution of Messages Acknowledged by Try Number for 0% Degradation.

The Bit Boxes (MODEMs that convert between Frequency Shift Keyed (FSK) TACFIRE signals and standard RS-232 signals) do not prevent collisions from occurring; therefore, even "perfect" communications, wasn't. The FIST DMD contained a "net monitoring" function to reduce message collisions. This feature was not implemented in the Bit Boxes, and it was originally believed that the lack of this was the reason for most of the collisions; however, this was not the case. Of the 4764 messages that were sent during the second half of the experiment under "perfect" communications conditions, 109 had to be sent more than once. There was only one collision resulting from two original messages being transmitted simultaneously; the rest were collisions between a message and an acknowledgement (ACK). A look at these messages revealed that 3 out of 4 of them were sent from the FIST DMD (the rest were sent from the simulators). This exposed a basic problem, not in the hardware, but in the ACE software. The actual TACFIRE hardware transmits ACKs immediately; however, those in the experiment normally took 2 to 3.5 seconds. This acknowledgment delay was more than enough to trigger the FIST DMD to retransmit the message. Hence, 3 out of 4 of these message collisions would not have happened in the "real world", or only about 25 of 4700 messages would have actually collided if the FOs were not listening to the net before transmitting. Whether the delay in the ACK was caused by the ACE Ether program or the simulators is not known; however, a new Ether program is being developed that will solve this problem, and the simulators can be modified to send acknowledgements faster.

3. Frequency Count of the Number of Receptions of a Given Message. As mentioned in a previous section many retransmissions of messages occurred in degraded communications. Retransmissions were necessary either because the message itself or its associated acknowledgement was deleted due to intentional communications degradation. If the message gets to its destination and the acknowledgment is deleted, duplicate copies of a given message can be received. The distributions of the number of times a given message was received at the FIST HQ for 15 and 30 percent degradation are shown in Figures 15 and 16, respectively. In 15-percent degradation, 17 percent of the messages received by the FIST HQ were duplicate receptions. In 30-percent degradation, 31 percent of the messages received were duplicate receptions. The FIST DMD does no checking for duplicate receptions of a given message, therefore, the burden was on the FIST HQ crew to recognize a message as a duplicate and delete it from the queue. The FIST HQ usually recognized duplicate messages, but occasionally would service a duplicate reception of a fire request or ATI message. If more than one copy of a given fire request was received by the FDS it would inform the FIST HQ that it was a duplicate target and not initiate another fire mission. Once, however, a FIST HQ sent one copy of a fire request to the FDS and a second reception of the fire request to the MFDS; both missions were run to completion.

Duplicate receptions cause serious problems when conducting a mission in the automatic mission mode. The FIST HQ crew do not process any messages except the original fire request messages in the automatic mission mode. Therefore, if the FIST DMD receives duplicate copies of non-fire-request messages, they are all forwarded. Furthermore, if the FIST DMD receives, say, two copies of a message from the FDS, they may in turn generate four copies of that same message at the FO because of retransmissions by the FIST DMD. In a worst case, each of the four automatic transmissions of a message by TACFIRE could be received by the FIST DMD and the FIST DMD could generate four copies of each automatically, meaning that the FO could possibly (although not probably) receive sixteen copies of a given message if no

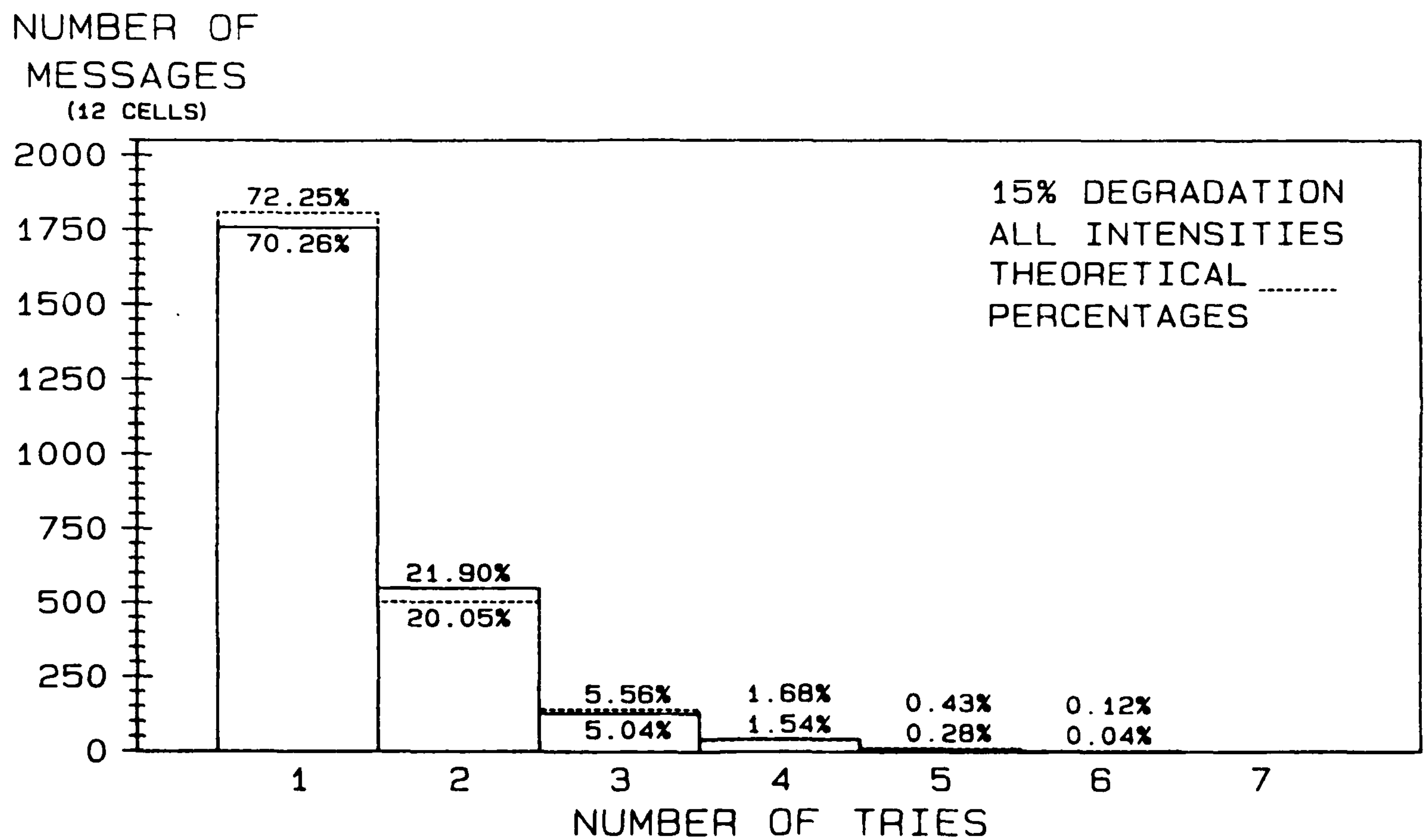

Figure 13. Distribution of Messages Acknowledged by Try Number for 15% Degradation.

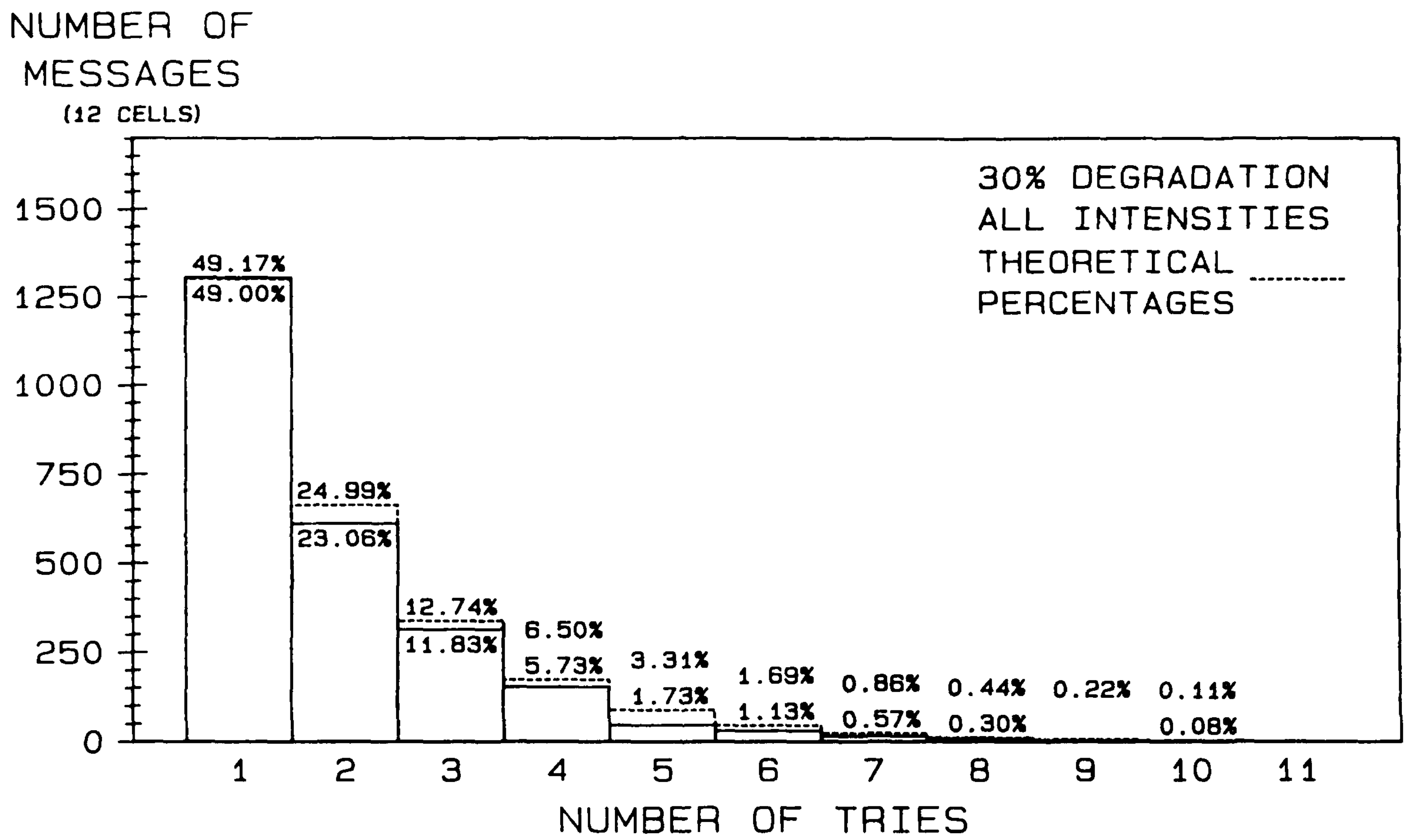

Figure 14. Distribution of Messages Acknowledged by Try Number for 30% Degradation.

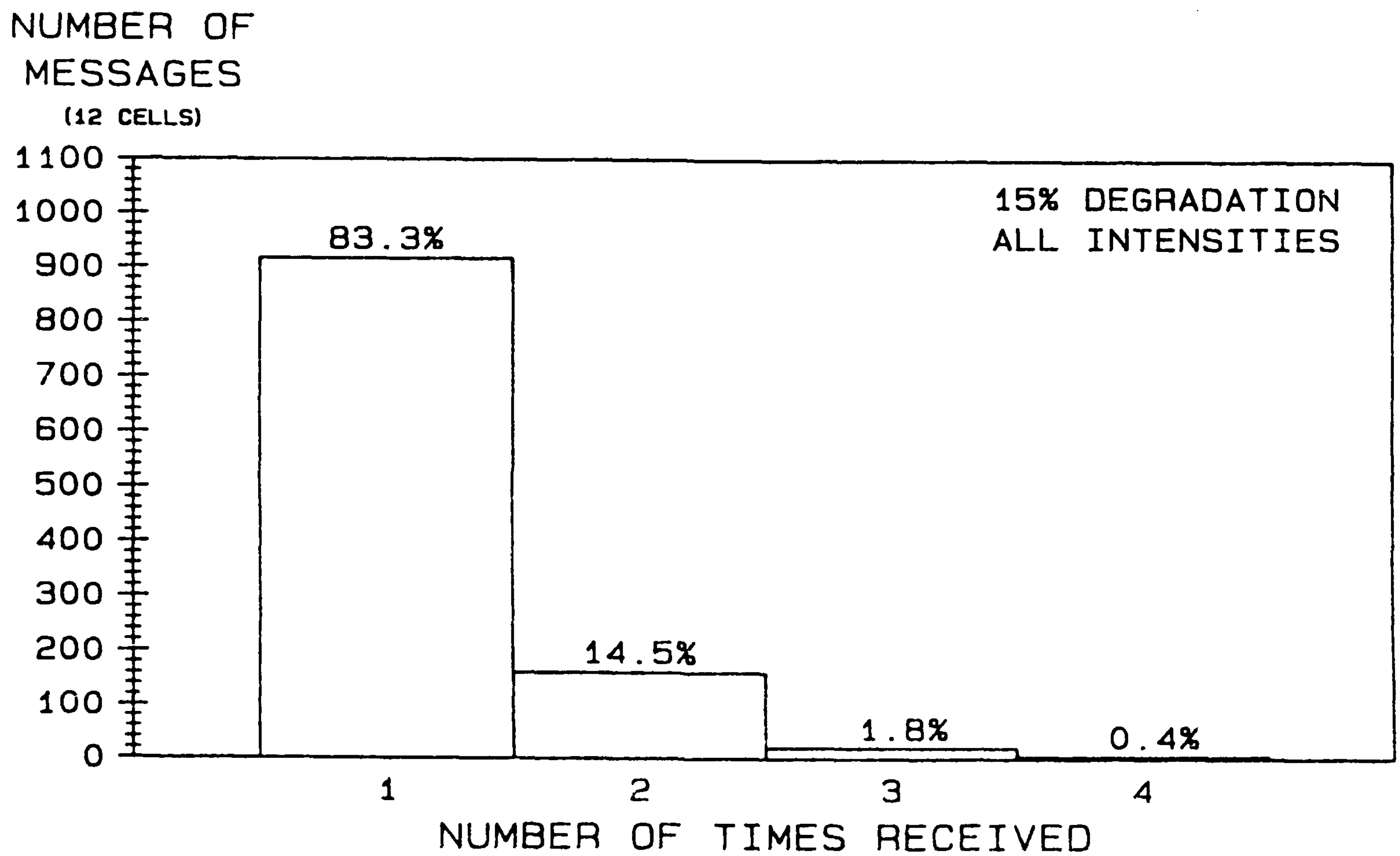

Figure 15. Distribution of Messages by Times Received for 15 Degradation.

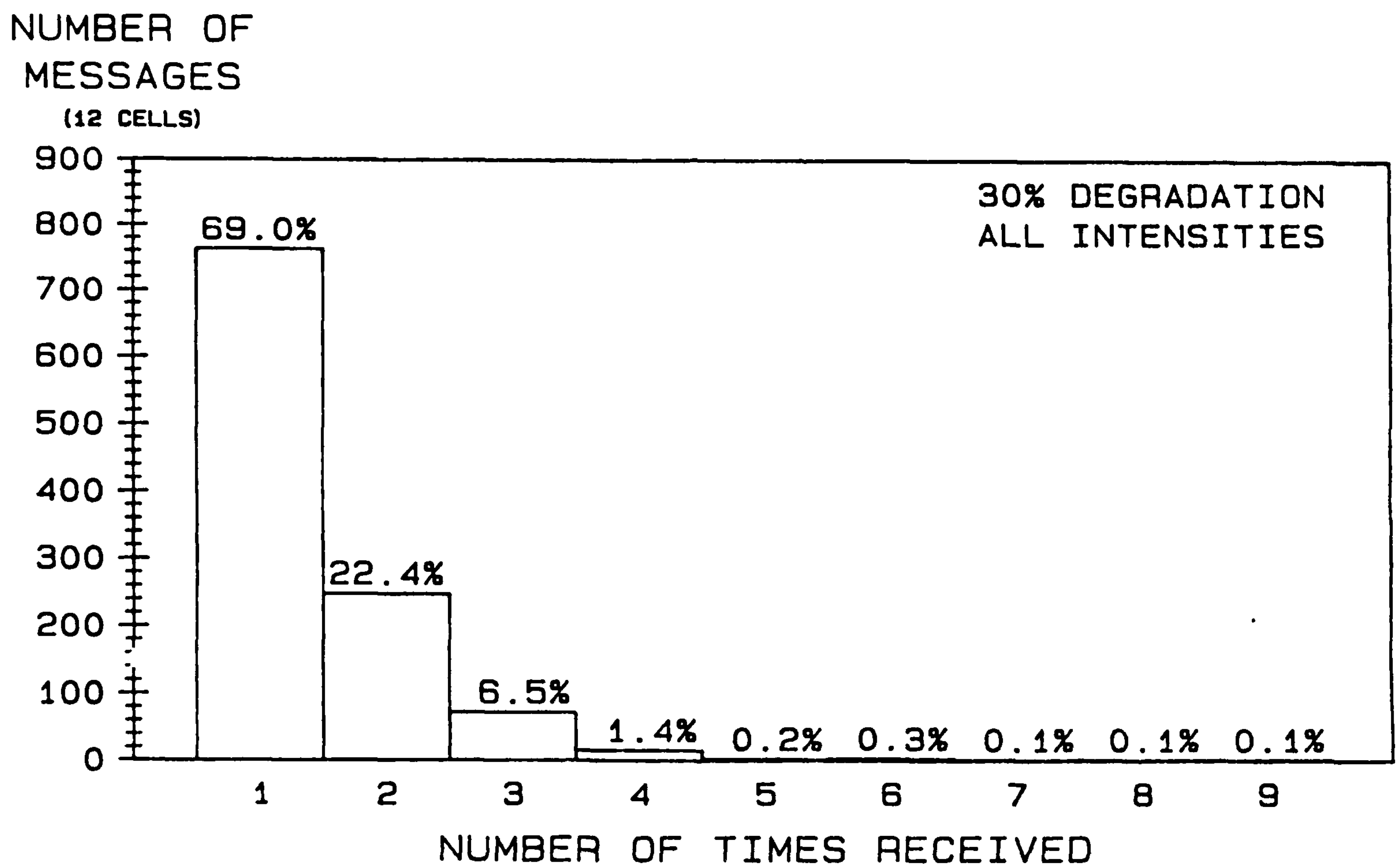

Figure 16. Distribution of Messages by Times Received for 30% Degradation.

acknowledgements are received and the automatic mission mode is being used.

4. <u>Time Required to Service a Message.</u> This section investigates the effect that degradation and intensity had on the time it took for FIST HQ 3 and 4 to service fire request (FR) messages and artillery target intelligence (ATI) messages. Only those teams tested under the second set of software were investigated here since software was a significant factor and since the second set of software was more realistic tactically. Since fire requests are given a higher priority than ATIs and require more processing by the FIST HQ crew, message type had to be considered a factor in this analysis.

As the data was checked for completeness, it was noted that the distribution of service time was skewed and that the variance of the observations under various experimental conditions exhibited discrepancies. A check for homogeneity of variance using Bartlett's test confirmed the latter observation. In addition, several experimental groups had observations that were extremely large (over four standard deviations from the group mean) and atypical of the majority of the service times observed under the same experimental conditions. These observations comprised slightly more than four percent of the total service times observed. They were removed from the analysis of variance procedure found below, but were considered in interpreting the final results below. The median for each experimental condition is given in Table 6.

Further investigation of the data revealed a positive correlation between the standard deviations and the experimental group means. Correlation between the standard deviations and group means is often accompanied by marked non-normality and non-homogeneity of variance, and indicates that the particular form of the original observations is unsuitable for ANOVA procedures. However, a transformation can be determined which makes the standard deviation independent of the mean, corrects non-homogeneity and also results in the observations being distributed more normally. In general, if a significant functional relationship between the standard deviation and the group means can be determined, then the transformation is the integral of the reciprocal of this functional relationship. Following this procedure, the following transformation was developed:

$$1.3 \ln(-2.6 + .8(\text{service time}))$$

The transformed data became more normal and the assumption of homogeneity of variance was confirmed.

An analysis of variance procedure was then performed on the transformed data. One slight modification to this procedure was that due to unequal experimental group sizes, the sum of squares for all terms in the model, except the error term, was weighted by the harmonic mean. The final reduced ANOVA table is presented in Table 7.

The most significant term in the analysis was team. The median service time for team 3 was 14.5 seconds which is substantially higher (73 percent) when compared to the 8.5 seconds for team 4. This trend is prevalent for both fire requests and ATI messages, but is magnified when one considers just fire requests. As suspected, type of message also influenced service

TABLE 6. Median Service Time
by Experimental Condition

Rep	Message	Team	Intensity	Degradation 0	Degradation 15	Degradation 30
1	ATI	3	L	9.2	12.0	27.0
			M	10.5	14.0	8.5
			H	9.0	14.5	23.0
		4	L	9.3	6.1	6.0
			M	6.5	6.5	9.0
			H	6.5	9.0	9.0
2	ATI	3	L	9.0	4.2	9.2
			M	9.5	10.3	9.5
			H	3.5	8.3	40.0
		4	L	6.3	7.8	5.5
			M	5.3	9.0	8.1
			H	7.5	6.5	11.5
1	Fire Request	3	L	15.5	22.0	46.0
			M	18.3	20.5	15.0
			H	17.3	16.0	21.5
		4	L	12.5	8.0	9.0
			M	6.3	8.5	9.3
			H	6.7	11.0	10.5
2	Fire Request	3	L	14.5	14.5	18.3
			M	14.3	16.7	18.5
			H	13.3	14.5	22.8
		4	L	8.0	9.5	8.0
			M	9.8	10.9	8.4
			H	11.3	8.8	17.5

time. Although fire requests have a higher priority than ATIs, they contain more information that has to be recorded and verified by the FIST HQ. Therefore, it was not surprising that the median time (13.5 seconds) for fire requests was 55 percent higher than the median service time (8.5 seconds) for ATIs.

TABLE 7. Analysis of Variance (Effect on Service Time)

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F RATIO
Replication	1	5.62	5.62	8.64**
Message Type	1	6.01	6.01	9.25**
Block within Rep	4	16.45	4.11	
Message Type X Block within Rep	4	7.36	1.84	
Team	1	150.98	150.98	232.3**
Team X Block within Rep	4	17.1	4.28	
Intensity	2	14.77	7.38	11.2**
Intensity X Message Type	2	9.48	4.74	7.18**
Intensity X Team	2	7.25	3.63	5.5**
Degradation	2	52.68	26.34	39.91**
Degradation X Message Type	2	5.52	2.76	4.18**
Degradation X Team	2	2.60	1.30	
Intensity X Degradation	4	31.68	7.92	12.01**
Intensity X Degradation X Team	4	11.99	3.00	4.54**
Pooled Error	790	520.9	.66	
Total	825	860.39		

The ANOVA table revealed that communications degradation and intensity had a significant effect on the FIST HQ service time. An increase in intensity or degradation resulted in an increase in the time it took for the FIST HQ to service a message. Because message type was also significant, the effects of intensity and degradation for each message type were considered separately. The median service time for ATIs increased 12 percent from low to high intensity as observed in the right marginal of Table 8. However, the FIST HQ ability to service fire requests remained essentially the same in either low or high intensity as shown in Table 8. One possible explanation is that as intensity increased, a larger proportion of the total effort was used to service the fire request messages because they were higher priority then ATIs. Consequently, ATIs were not serviced as quickly.

The effect that degradation had on service time is consistent with the above trend for both ATIs and fire requests. As observed in examining the bottom marginals of Table 8, an increase in degradation from 0 to 30-percent resulted in the FIST HQ median service time increasing 29 percent and 13 percent for fire requests and ATIs, respectively.

TABLE 8. Intensity by Degradation Median Service Time for Fire Requests (FRs) and Artillery Target Intelligence (ATIs) Messages

Intensity Level	Message Type	Communication Degradation (%)			
		00	15	30	All Levels
LOW	FRs	12.5	13.5	16.0	14.5
	ATIs	8.5	8.5	8.5	8.5
MEDIUM	FRs	11.5	13.5	12.0	12.0
	ATIs	7.5	9.5	9.0	9.0
HIGH	FRs	12.0	13.0	17.5	14.0
	ATIs	7.0	9.5	19.5	9.5
All Levels	FRs	12.0	13.0	15.5	
	ATIs	8.0	9.0	9.0	

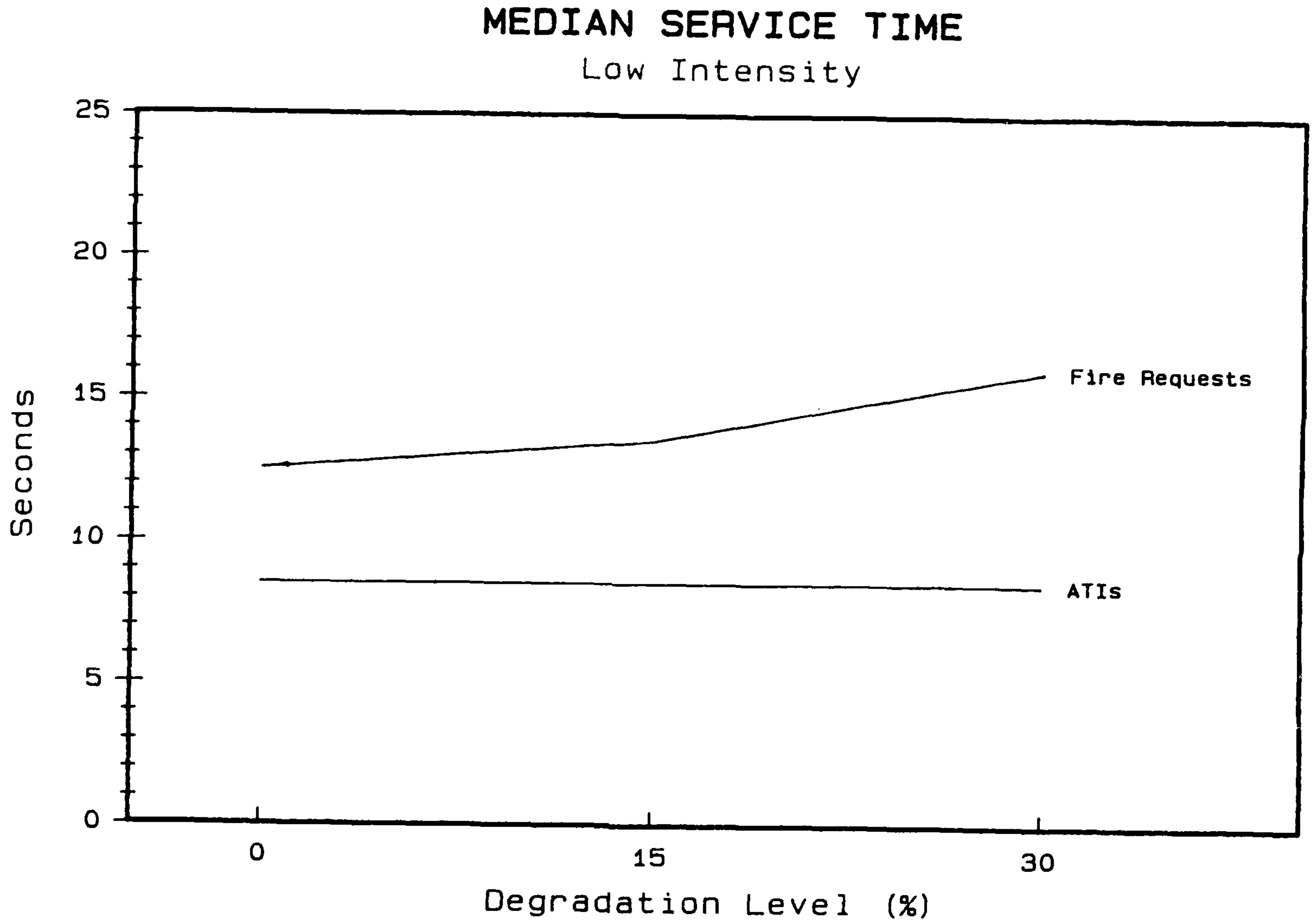

Figure 17. Median Service Time for Low Intensity.

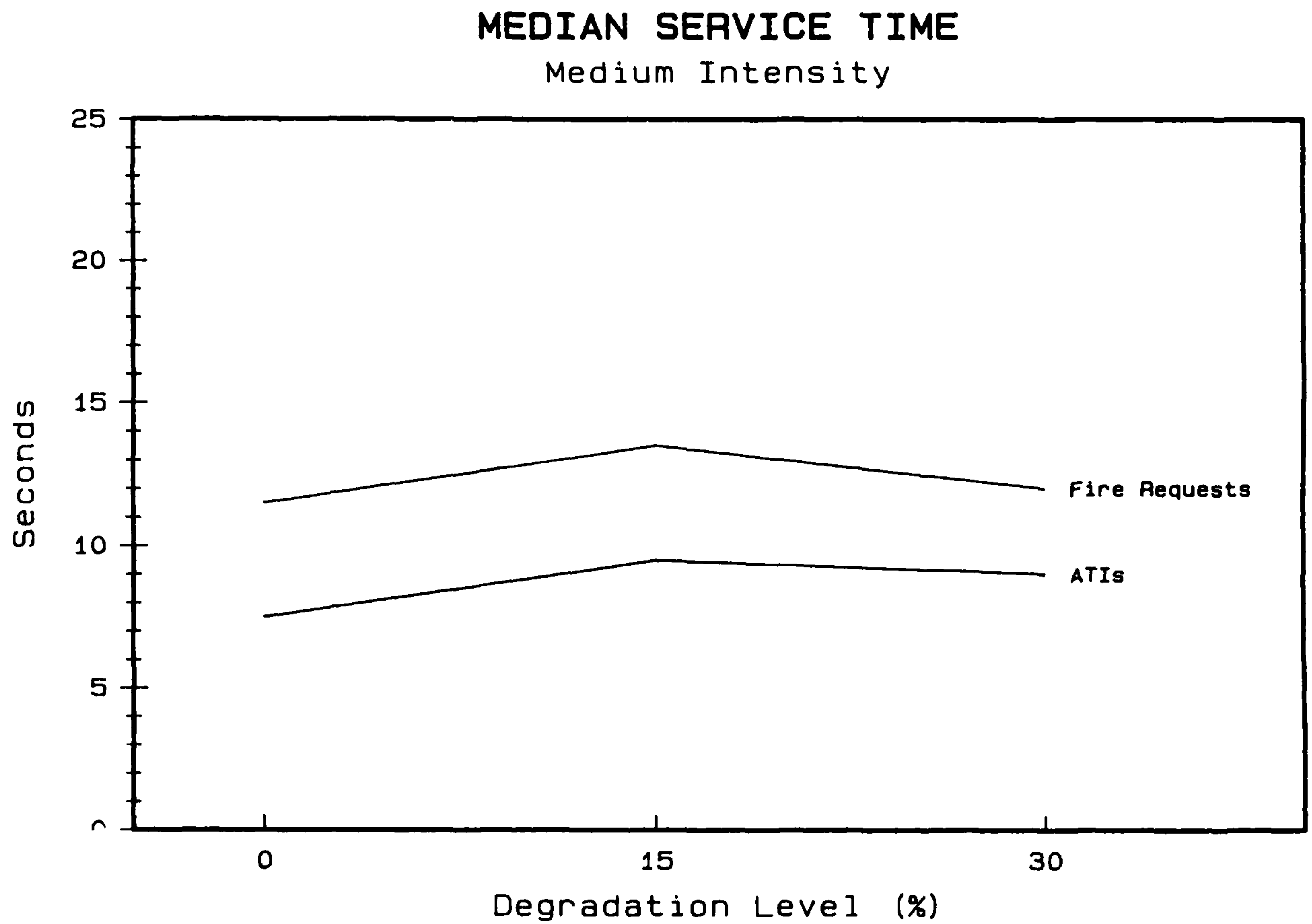

Figure 18. Median Service Time for Medium Intensity.

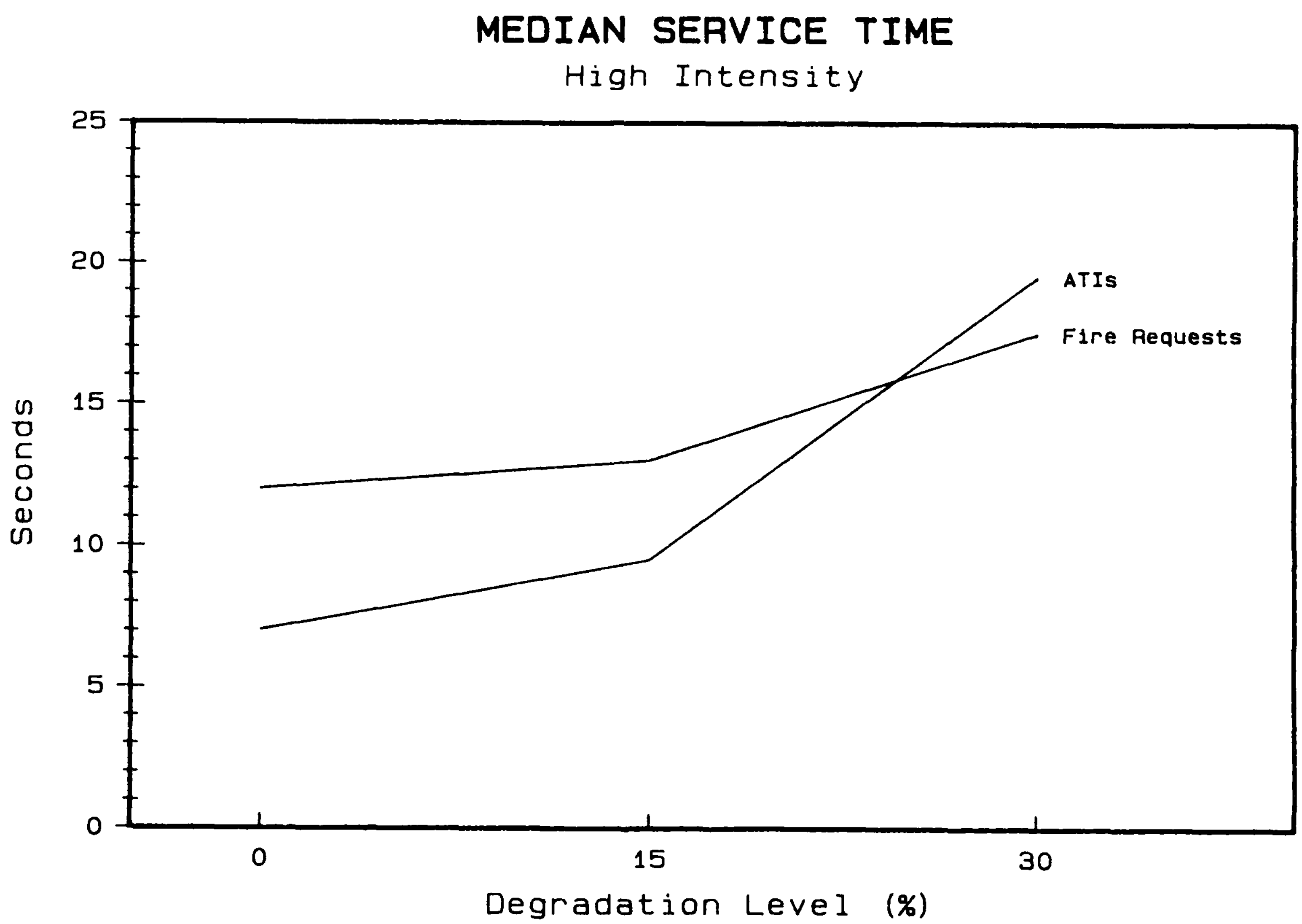

Figure 19. Median Service Time for High Intensity.

For ATIs, the median service time increased only slightly as degradation increased from 0 to 30 percent for low or medium intensity as shown in Table 8 and Figures 17 and 18. Similarly, for fire request messages, the service time increase from 0 to 30 percent degradation was only 4 percent in medium intensity. This trend was more noticeable in low intensity where the median FIST HQ service time for fire requests increased almost 28 percent as degradation increased from 0 to 30 percent. However, in high intensity, the increase from 0 to 30 percent degradation resulted in a substantial increase in service time for both ATIs and fire request messages when compared to any increase observed in low or medium intensity. The median service time for fire requests increased 46 percent from 0 to 30 percent degradation and for ATIs increased 179 percent. This was due to the fact that the largest median service time observed for ATIs and fire requests occurred under 30 percent degradation and high intensity. In addition, it was only under this condition that the median service time (19.5 seconds) for ATIs was higher than the median service time (17.5 seconds) for fire requests, as depicted in Figure 19. This seems to substantiate the hypothesis that under increased workload, the FIST HQ spends more time trying to service fire request messages while ATIs are left in the DMD queue. It also may mean the point was reached at which fire support coordination operations begins to seriously degrade.

Although replication (learning) was significant, only a slight decrease (8 percent) in service time was observed between replicate 1 and replicate 2.

The final step in this analysis was to categorize the removed data (outliers) by various experimental conditions. The following trends were worth noting. Of the 36 service times removed from the data base, over one third were observed under 30 percent degradation and high intensity. In addition, 75 percent were observed from 30 percent degradation with over 92 percent coming from two-hour cells that were run under 15 or 30 percent degradation. These observations substantiate the hypothesis that increased degradation and the combined effect of 30 percent degradation and high intensity causes unpredictable delays for the FIST HQ in servicing messages.

5. Manual Transmission Time Distribution. Manual transmission time is defined to be the time between the first transmission of a message by the FIST DMD operator until an acknowledgement is received for that message. *Manual* transmission time was computed using only fire request and artillery target intelligence message types since these were the only message types (excluding freetext) which were not automatically forwarded by the FIST DMD in automatic mission mode. Transmission time for both of these initiating message types was found to be greatly affected by the percent of communication degradation in the communication networks. This is consistent with results found for the frequency count of messages by number of transmissions; that is, the more transmissions required until an acknowledgement was received, the longer the transmission time. The time it took for a message to successfully reach its destination and for an acknowledgement to be received by the FIST increased with an increase in degradation. This trend is evident in Figures 20 thru 22 which show the distribution of manual transmission times less than 180 seconds for 0, 15 and 30-percent degradation, respectively. All messages in 0 percent degradation took less than 180 seconds and are shown on Figure 19. Two transmission times, one at 251 and the other at 273 seconds are not shown on the distribution for 15 percent degradation, but are reflected in the statistics computed. Nine service times are not shown in 30 percent degradation. They occur at 186, 209, 216, 222,

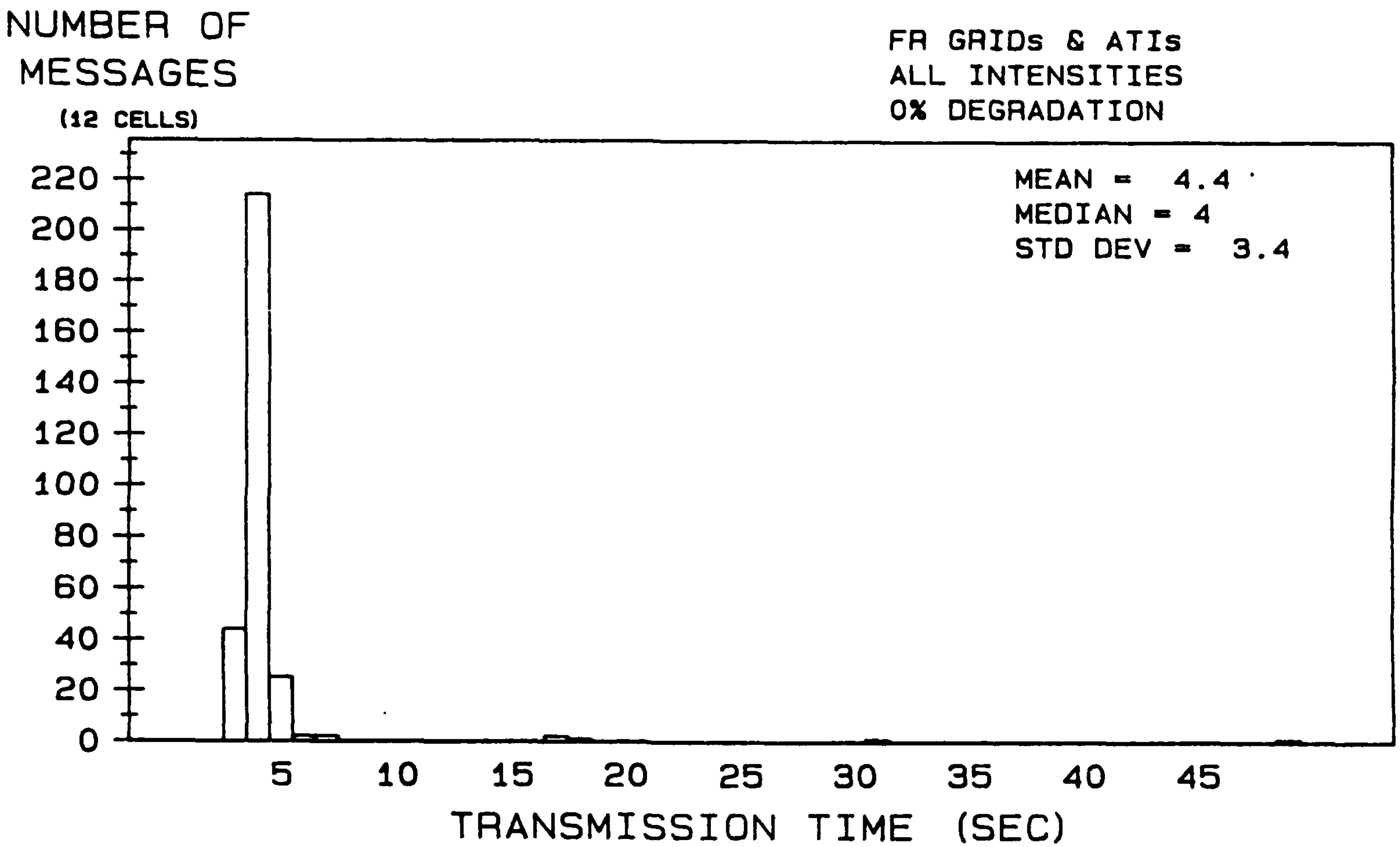

Figure 20. Distribution of Transmission Times for 0% Degradation.

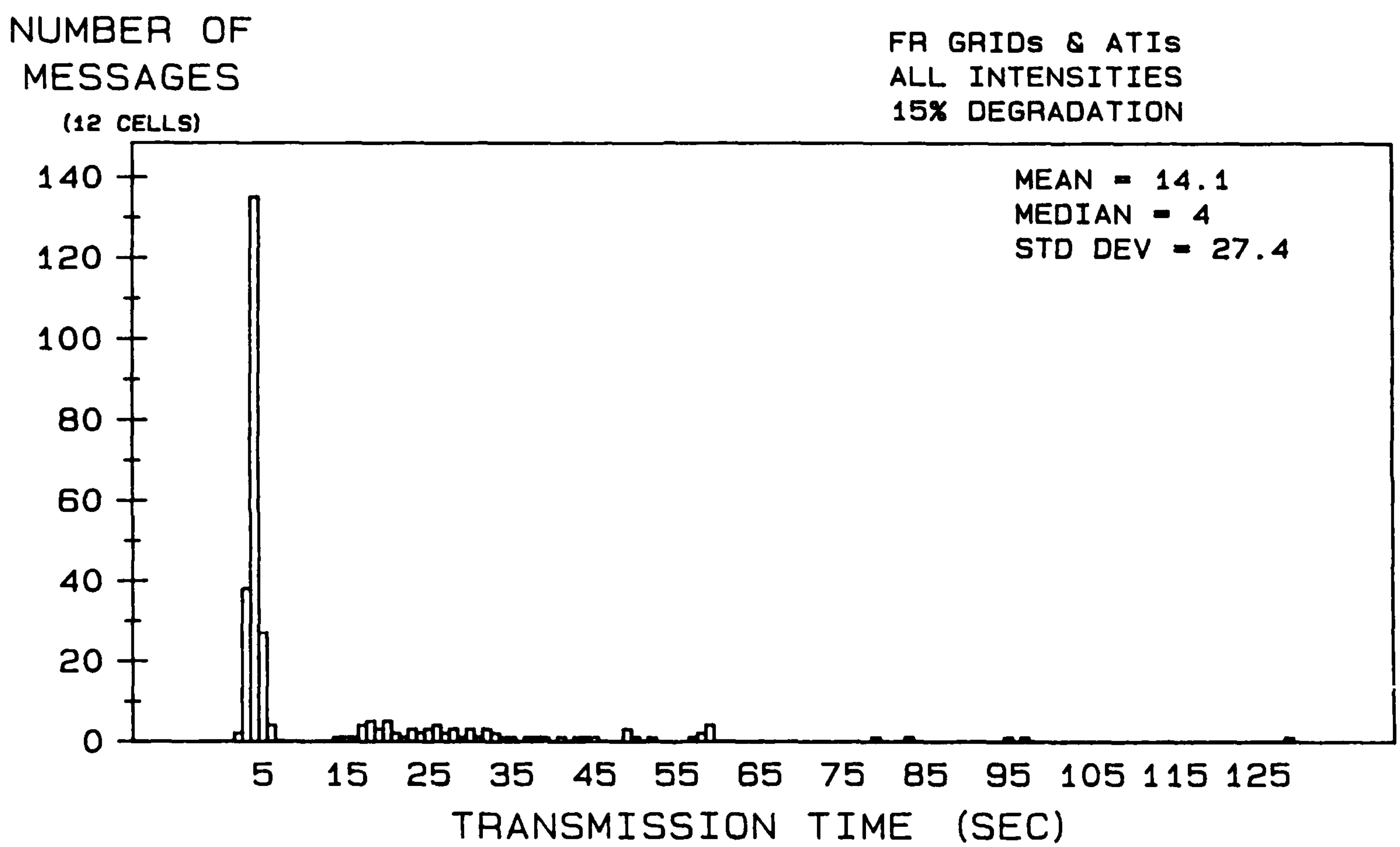

Figure 21. Distribution of Transmission Times for 15% Degradation.

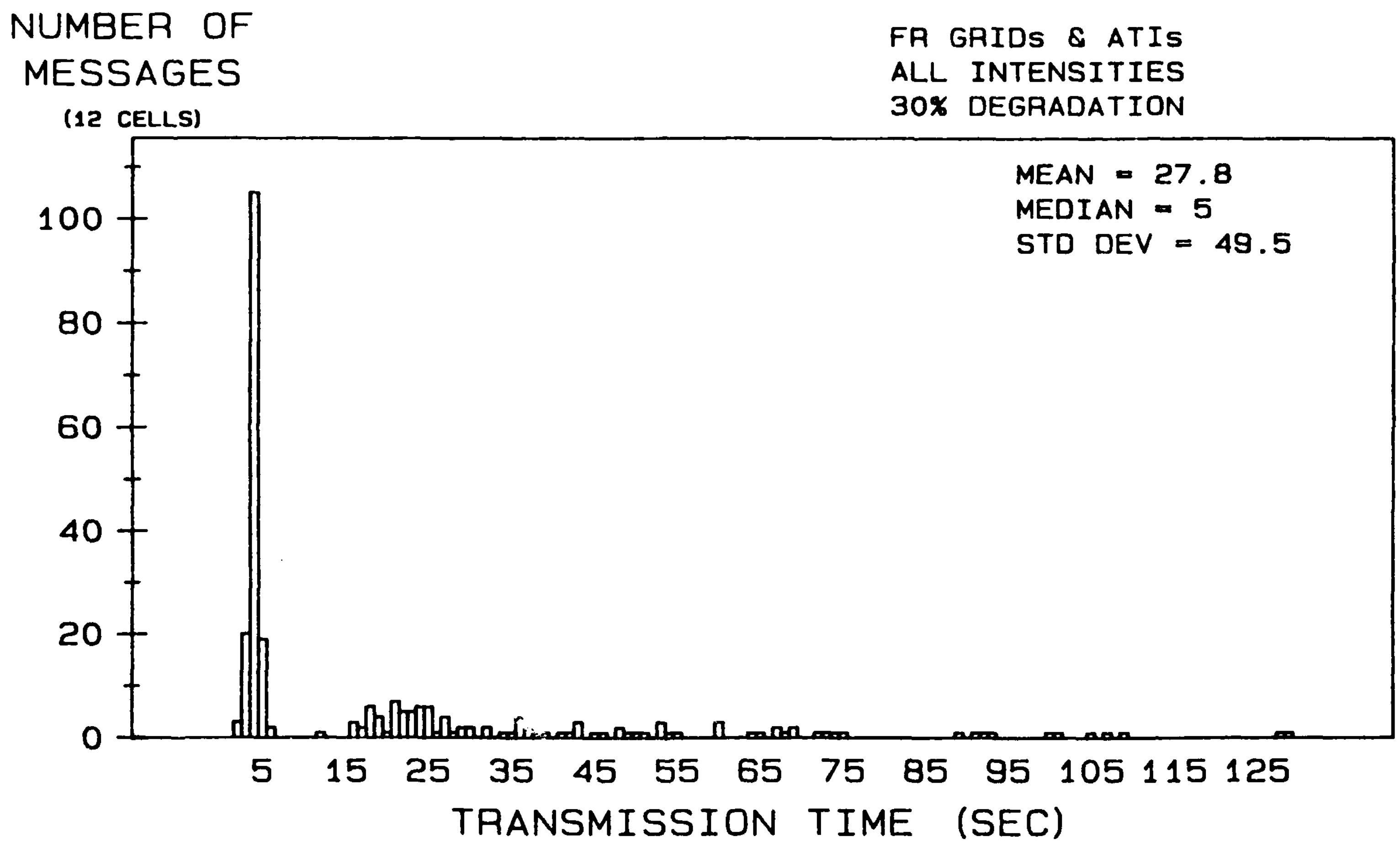

Figure 22. Distribution of Transmission Times for 30% Degradation.

271, 272, 291, 302, and 303 seconds, but are again reflected in the statistics computed. At 0 percent degradation, over 97 percent of the messages took less than 7 seconds. This percentage decreased for 15 and 30 percent degradation where only 72.5 percent and 56 percent of all initiating messages took less than 7 seconds, respectively.

Intensity had no significant effect on transmission time. Between 73 and 77 percent of all messages had a transmission time less than 7 seconds for all intensity levels. In conclusion, the only factor that had any significant effect on transmission time was communication degradation.

6. Number of Missions Initiated, Completed and Expected. A *completed* fire mission includes a call for fire, MTO, at least one SHOT and an end-of mission (EOM). An *initiated* fire mission by definition is a call for fire (FR GRID) followed by a message-to-observer (MTO). The number of *expected* fire missions is the number of fire missions in the database. Table 9 gives the number of missions completed, initiated and expected for each intensity level.

TABLE 9. Number of Missions Initiated, Completed and Expected

INTENSITY	TOTAL # COMPLETED MISSIONS	TOTAL # INITIATED MISSIONS	TOTAL# EXPECTED MISSIONS
LOW	73	75	72
MEDIUM	156	157	156
HIGH	227	229	228

The total number of initiated missions is larger than the expected number of missions for each intensity. This is largely due to the inability of the FIST HQ to distinguish between duplicate calls for fire. Since the FIST HQ believed these duplicate fire requests to be new calls for fire, the messages were forwarded to the FDS or MFDS at the teams' discretion. In three instances, the FDS received one copy of the fire request while the MFDS received another. In one case, the FDS received two copies of a FR (at different time intervals) from the FIST HQ during a 30 percent degradation cell. This type of oversight during degraded communications was not unique to any one FIST HQ.

Confusion caused by heavy message traffic can be seen in one particular high intensity, 30-percent degradation cell. During the two hours and ten minutes of testing, two fire missions were canceled because the MFDS was busy (MFDS can run only one mission at a time; the fire requests could have been sent to the FDS), but the FIST never re-initiated the calls for fire or re-routed the requests to the FDS. As a result only 17 out of the 19 expected missions were completed. During a low intensity, 0-percent degradation cell, FIST 3 spuriously sent a SA (subsequent adjust) LASER mission. This fire mission was never completed.

B. Analysis of Questionnaires

The FIST HQ were required to fill out questionnaires at the end of the FIST DMD training phase and at the end of the test. Mr. Leonard Cunningham and Major Grim of the Field Artillery Board developed the questionnaires for the FIST Force Development Testing and Experimentation (FDTE). (See Appendix B for sample questionnaires.) Seventeen of the FIST HQ members filled out the end-of-training questionnaire. Twenty team members filled out the end-of-test-questionnaire.

1. End-of-Training Questionnaire. Part I of this questionnaire was designed to provide information on the FIST HQ members' educational background and previous military experience. All of the team members reported having at least a high school education. All of them had previously worked as a member of a fire support team with their experience ranging from one month to seven years. A majority of the team members (14 of 17) were FIST members just before coming to HEL for the test. A majority of the team members (15 of 17) had also taken an ARTEP as a member of a FIST HQ and rated their teams' ARTEP performance as either excellent or superior. Eleven of the seventeen team members had received their 13F MOS through the Army Institute of Technology (AIT). Four team members had been trained through the Field Artillery Officer's Basic Course (FAOBC). The remaining two subjects had received on-the-job-training. Only two of the seventeen team members had prior experience with a DMD and of these two, one rated himself as "good" and the other as "outstanding" at its operation. The majority of the team members (14 of 17) had not operated any TACFIRE devices.

In the second part of the end-of-training questionnaire the team members evaluated the training session. The majority (14 of 17) of them thought sufficient time had been spent in training. Most of the team members (12 of 17) reported the classes were well organized and the vocabulary understood. They also reported the platform instructions were clear and concise and the objectives of the lessons clearly stated (14 of 17). There was, however, uncertainty as to whether the situations presented in the instructions were realistic. Eight of the 17 team members said the situations were realistic. Whereas five of them said they were not realistic and four team members were uncertain. The majority of the team members (14 of 17) reported that the FIST DMD became easy to operate in the time allotted for training. They also said the tasks in the manual were explained clearly (12 of 17). The majority of the team members also said they understood the manual (9 of 15) and could use its directions to perform a task (14 of 17).

In Part III of this questionnaire the team members distinguished between those tasks they had performed, those tasks they were taught but had not performed, and those tasks they were not taught. The majority (10 of 17) of the team members reported having been taught all of the tasks on the list. Twenty-eight of the 42 tasks listed in this section were reported as having been performed by all the team members.

In Part IV of the end-of-training questionnaire, the FIST HQ members were asked if they had any problems operating the FIST DMD and, if so, if they had solved the problems. Twelve of the 16 team members reported having no problems with the DMD. Of the four team members who reported having problems with the DMD, three said they had solved the problem. Fourteen of the 16 team members said they could operate a FIST DMD under most circumstances. The other two team members did not think they could operate the DMD under conditions of communication degradation.

2. End-of-Test Questionnaire. Part I of the end-of-test questionnaire was exactly the same as Part II of the end-of-training questionnaire. The FIST HQ members were asked to remember their training session in answering the questions. Their responses were basically the same as they had been for this section in the end-of-training questionnaire. The majority of the team members (16 of 20) thought sufficient time had been spent in training. They also reported the platform instruction was clear and concise with the vocabulary understood. Twelve of the twenty team members thought the situations in the instructions were realistic and the tasks in the manual explained clearly. Four of the team members were uncertain about the realism of the situations and the clarity of the tasks in the manual. The other four of them thought the situations were unrealistic and the tasks not explained clearly. The majority of the team members thought the classes were well organized (18 of 20) and the objectives of the lessons clear at the beginning (14 of 20). Also, the majority of the team members (18 of 20) indicated the equipment was easy to operate in the time allotted. Most of the team members (16 of 20) could understand the manual and use it to perform a task.

Part II of the end-of-test questionnaire consisted of a list of tasks which were the same tasks as in Part III of the end-of-training questionnaire. The team members were asked to check off those tasks they had performed during the test and then to rate their performance on the task. They used the following code in rating their performance: 1-needed a lot of help to perform task; 2-needed some help to perform task; 3-needed no help to perform task, but was slow; 4-performed task quickly with no help and no problems.

Several of the tasks in this part of the end-of-test questionnaire were not performed by any of the team members. For those tasks which the team members did perform, the majority rated themselves with a four for each task. This indicated that the team members believed they performed the tasks quickly with no help or problems. All of the team members except one reported they could operate and maintain the FIST DMD under most conditions. Sixteen of the twenty team members reported they did not have any problems operating and maintaining the FIST DMD as a result of inadequate training. Of the other four team members, one did not answer this question, two failed to say what problems they had had, and one team member reported he needed more field training.

VI. CONCLUSIONS

Software, intensity, communication degradation, software-intensity interaction and intensity-degradation interaction all had a significant effect on message traffic through the FIST HQ. A change from 0 to 15-percent communication degradation resulted in an average increase of 33 percent in the number of messages generated. A change from 0 to 30-percent communication degradation resulted in an average increase of 73 percent in the number of messages generated. Medium intensity generated 75 percent more messages than low intensity and high intensity generated 144 percent more messages than low intensity, on the average. Software was added as a factor in the experiment to control for the variance induced by the change in software. Knowing that the change between software versions was significant and the second set of software was more correct tactically, only the second half of the test was analyzed for the other measures.

Since the FIST DMD allows only four transmissions and then voice contact must be made to resynchronize authenticator codes, the number of transmissions of a given message before an acknowledgement is received is important. Voice transmissions on digital nets cause net contention. In 15 percent degradation .3 percent of the messages required more than four transmissions and in 30 percent degradation 6.4 percent of the messages required more than four transmissions. Although these percentages are small, the total number of messages is quite large, and the actual number of voice transmissions required may be tactically significant. It is important to also note that fire direction net usage ranged from 2.6 to 10.0% with only one of the three or four FISTs operating and without the message traffic between TACFIRE, BCS, and VFMEDs; therefore, net contention could be a serious problem when the net is fully loaded.

The median service time for messages was influenced significantly by team, message type, replication, intensity, degradation, and many of the interaction terms. It is not surprising that when measuring a human response time that the humans, in the FIST HQ, are the most significant factor. Replication being significant in this instance can be translated to a slight learning effect since the first replicate occurred on the first three days of testing and the second replicate occurred on the last three days. An increase of 32 percent in median service time for fire requests and ATIs combined was observed from 0 to 30-percent communications degradation and an increase of 34 percent was observed as intensity increased from low to high. The combined effect of intensity and degradation is most noticeable in high intensity. That is, communication degradation has little effect within low intensity or medium intensity, but has a very large effect in high intensity. Although fire requests take longer to process, in general, than ATIs, as communication degradation increases within high intensity, the rate at which service time (which is both the time spent in the FIST DMD queue and the human processing time) increases for ATIs is considerably higher than the rate of increase for fire requests. Consequently, at 30 percent degradation ATIs take longer to process than fire requests. Service time in high intensity increases 179 percent for ATIs and 46 percent for fire requests. What this would indicate is a queueing problem at the FIST HQ. Fire requests are higher priority than ATIs and are selected out of the queue before ATIs for processing. Therefore, although it may not take as long to process ATIs, they are remaining longer in the FIST DMD queue until finally their service time exceeds that of fire requests. Data also seems to indicate that high intensity and 30-percent communications degradation was the point at which fire support coordination operations began to seriously degrade (See Figure 18).

Many software enhancements were recommended for the FIST DMD; nearly all of them have been implemented by the developers and added to the FIST DMD specification. For example, new messages entering the input queue will now be compared with the others in the queue and discarded if they are duplicates. Several functional problems were also identified and reported to the developers. For example, the FIST DMD failed to reset the try number to zero before forwarding messages in the automatic mode. If a message took more than one try to reach the FIST DMD, the number of tries available to the FIST HQ to forward the response message was reduced. This also would disrupt the authentication sequence used by TACFIRE and increase the number of times the FIST HQ would have to establish voice contact to resynchronize authenticator codes.

In summary, the feasibility of using the automated techniques of ACE and the CPX Research Facility for performing fire support control experiments and for training soldiers in the operation of the FIST DMD was successfully demonstrated.

VII. ACKNOWLEDGEMENTS

The authors wish to express their appreciation to The Fire Support and Target Acquisition Directorate of HEL, The Artillery Systems Concepts Branch of BRL and to Annette Wiseman for formatting this report.

APPENDIX A

CONTINGENCY TABLE ANALYSIS

APPENDIX A
(Contingency Table Analysis)

Contingency table analysis is a method used to make direct inferences about whether two or more population distributions are identical to some theoretical form. Ordinarily, the reason for comparing such distributions is to find evidence for independence of attribute or experimental conditions. In short, we employed a test for independence for each experimental unit in our design matrix.

The general procedure is to statistically compare the sample or observed frequency for each experimental unit to the theoretical expected frequency.

The statistic used to test if the observed frequency for each treatment combination is equal to the expected frequency is the chi-square statistic. This statistic is defined as

$$\sum_{i=1}^{i=N} \frac{(f_i - e_i)^2}{e_i}$$

where N is the number of experimental units and f_i and e_i are the observed and expected cell frequencies, respectively. The calculated statistic is then compared to a tabulated value which is based on an alpha level equal to .05 and the number of degrees of freedom associated with the analysis. The number of degrees of freedom is equal to the number of experimental unit minus one, minus the number of parameters estimated from the sample data which are needed to determine the expected frequency. If the calculated chi-square statistic is larger than the tabulated value, the hypothesis that the experimental treatments are not associated with the MOP being analyzed is rejected. One restriction is that the sample size must be sufficiently large so that none of the theoretical frequencies are less than 1 and not more than 20 percent are less than 5.

For MOP2, which is the frequency count of the number of times a message is sent before it is acknowledged, the theoretical distribution could be determined for each treatment combination without any sample results. At zero percent degradation, the probability of having a try number greater than zero, which can be interpreted as the probability of a message not getting through and/or an acknowledgement not being returned on the first try, is zero. At fifteen percent degradation, the probability of a message getting through and an acknowledgement returned on the first try is recorded for each two-hour block run with 15% degradation to have a try number of zero. Similarly, with 30% degradation, one would expect 49 percent of the total messages recorded per two hour block to have been tried only once. The theoretical probability by try is given in Tables A-1 and A-2.

It was originally decided that three separate contingency table analyses would be performed for each level of communication degradation. However, at zero percent degradation all of the messages should have been acknowledged after the first try. The expected number of messages by try number for the 24 cells run at each level of communication degradation is presented in Table A-3. It is worth noting that since no parameter estimation was needed to determine these theoretical distributions, the degrees of freedom for each analysis was equal to the number of cells minus one. These theoretical frequencies were compared to the observed

TABLE A-1. Probability of a Message Being Acknowledged by Try (15% Degradation)

Degradation	Try 1	2	3	greater 3
15 %	.723	.201	.056	.021

TABLE A-2. Probability of a Message Being Acknowledged by Try (30% Degradation)

Degradation	Try 1	2	3	greater 3
30 %	.490	.250	.128	.132

frequencies using the above described procedure. Then, using the contingency table analysis outlined above, can determined if the other experimental factors had an effect on the number of tries it takes before a message is acknowledged.

The first step of this analysis was to verify that the uniform random number generator did produce fifteen and thirty percent total message loss for each set of twelve cells run under the modified software. Using the chi-square statistic defined above, one could test if in fact the observed and expected number of messages never degraded under 15 and 30 percent degradation were statistically the same.

For fifteen percent degradation, the chi-square statistic was calculated as 2.257 with 11 degrees of freedom and found not significant at alpha equal to .05. Similarly, at 30 percent degradation, the statistic was calculated as 1.175 with 11 degrees of freedom and again found not to be significant. In fact, over each set of twelve cells, it was calculated that .8525 and .7054 of the messages were never degraded for 15 and 30 percent degradation, respectively.

Having verified that Ether was producing the desired degradation levels in our communication network, the next step was to determine if intensity and team variability had an effect on the distribution of message tries for acknowledged messages at each degradation level.

At 0 percent degradation, one would expect all of the messages to be acknowledged on the first try. As seen from Table A-3 below, almost all (98.6%) of the messages had successfully been sent and acknowledged. It is obvious that intensity and team variability had no effect on a message reaching its destination at zero percent degradation. The 1.4 percent of the messages that did not get through on the first try could be attributed to Bit Box collisions which is a

TABLE A-3. Observed Number of Messages Acknowledged by Try (00% Degradation)

Rep	Software	Team	Intensity	Try 1	Try 2	Try 3
1	2	3	L	134	9	1
			M	192	3	0
			H	265	0	0
		4	L	121	1	0
			M	201	3	0
			H	277	3	0
2	2	3	L	112	2	0
			M	192	4	0
			H	269	2	0
		4	L	116	2	0
			M	198	2	0
			H	271	2	0

hardware phenomena. This phenomena occurs when two messages enter the Bit Box on opposite ends simultaneously, collide and then are lost.

A contingency table analysis was performed on the 12 two-hour cells run at 15 percent communication degradation. The observed number of messages acknowledged for try one, two, three and tries greater than three was compared to the expected number. The calculated chi-square statistic was 44.2 with 47 degrees of freedom. This statistic was not statistically significant and one could only conclude that the observed and theoretical distributions were the same.

For 30 percent degradation the contingency table analysis again revealed that intensity, team variability and replication did not influence the number of tries it took for a message to be acknowledged. The chi-square statistic was 30.29 with 59 degrees of freedom.

In conclusion, based on our experiment, we demonstrated that the number of tries it takes before a message is acknowledged is a function of the percent degradation exhibited in the communications network and it is not statistically influenced by intensity, team variability or replication. The theoretical and actual frequency distributions by try number are given in Tables A-4 through A-7 for 15 and 30 percent communication degradation, respectively.

TABLE A-4. Observed Number of Messages Acknowledged by Try (15% Degradation)

Rep	Software	Team	Intensity	Try 1	Try 2	Try 3	Try greater 3
1	2	3	L	96	29	5	3
			M	153	57	17	2
			H	194	47	18	6
		4	L	76	35	6	3
			M	166	41	11	3
			H	197	69	12	6
2	2	3	L	92	22	2	3
			M	143	48	8	4
			H	197	71	14	7
		4	L	88	37	12	5
			M	150	45	10	8
			H	206	61	13	4

TABLE A-5. Expected Number of Messages Acknowledged by Try (15% Degradation)

Rep	Software	Team	Intensity	Try 1	Try 2	Try 3	Try greater 3
1	2	3	L	96	26.7	7.5	2.7
			M	165.5	46.0	12.8	4.7
			H	191.5	53.3	14.8	5.4
		4	L	86.7	24.1	6.7	2.5
			M	159.7	44.4	12.4	4.5
			H	205.2	57.1	15.9	5.8
2	2	3	L	86	24	6.7	2.4
			M	146.6	40.1	11.4	4.2
			H	208.8	58.1	16.2	5.9
		4	L	102.6	28.5	7.9	2.9
			M	153.9	42.8	11.9	4.4
			H	205.2	57.1	15.9	5.8

TABLE A-6. Observed Number of Messages Acknowledged by Try (30% Degradation)

Rep	Software	Team	Intensity	Try 1	Try 2	Try 3	Try 4	Try greater 4
1	2	3	L	68	34	26	8	12
			M	94	71	29	13	12
			H	154	63	41	23	19
		4	L	67	34	14	8	8
			M	106	62	30	14	12
			H	150	73	33	13	18
2	2	3	L	64	23	18	11	10
			M	115	52	32	10	16
			H	150	74	43	18	17
		4	L	65	34	15	7	9
			M	111	56	24	14	14
			H	161	101	32	27	22

TABLE A-7. Expected Number of Messages Acknowledged by Try (30 % DEGRADATION)

Rep	Software	Team	Intensity	Try 1	Try 2	Try 3	Try 4	Try greater 4
1	2	3	L	72.6	37	18.9	9.6	10
			M	107.4	54.7	27.9	14.2	14.8
			H	147	75	38.3	19.5	20.3
		4	L	64.2	32.7	16.7	8.5	8.8
			M	109.8	56	28.6	14.6	15.1
			H	140.6	71.7	36.6	18.7	19.4
2	2	3	L	61.7	31.5	16.1	8.2	8.5
			M	110.3	56.2	28.7	14.6	15.2
			H	148	75.5	38.5	19.6	20.4
		4	L	63.7	32.5	16.6	8.5	8.8
			M	107.3	54.7	27.9	14.2	14.8
			H	168.1	85.7	43.7	22.3	23.1

APPENDIX B

FIST DMD OPERATOR'S TRAINING

QUESTIONNAIRE

APPENDIX B

FIST DMD OPERATOR'S TRAINING

QUESTIONNAIRE

NAME ____ RANK ______________________

UNIT ____ SSAN ______________________

MOS ____________________ NUMBER OF MONTHS IN MOS ________________________

Circle the highest grade you completed in school.

1 2 3 4 5 6 7 8 9 10 11 12 GED 13 14 15 16 OVER 16

The purpose of this questionnaire is to gather data about your operator's training on the FIST DMD. These questions ask you about the FIST DMD training and the training materials. They also ask about tasks you learned during your school training. Answers will be used to determine if the training should be changed to obtain better results in the field. After discussing each task, you have the opportunity to comment on any phase of the training.

Your observations will be used in making the training evaluation.

<u>REMEMBER!! GIVE YOUR HONEST OPINION</u>

PART I

The following data will be used for statistical purposes only. Please answer each question as accurately as possible.

1. a. Have you ever worked as a member of a fire support team?

Yes____ No____

b. If yes, how long? Years_____ Months_____

2. Were you assigned to a fire support team just before you came here?

Yes_____ No_____

3. a. Have you ever taken an ARTEP as a member of a fire support team?

Yes_____ No_____

b. If yes, how well did the fire support team do?

Superior_____ Excellent_____ Good_____ Fair_____ Poor_____

4. Did you get your MOS, 13F, through AIT or on-the-job training?

AIT_____ OJT_____ FAOBC_____ No Ans_____

5. a. Have you had experience with a digital message device before you came here for the test?

Yes_____ No_____

b. If yes, how well could you operate the DMD?

Outstanding_____ Excellent_____ Good_____ Fair_____ Poor_____

6. Place an X by the TACFIRE devices you have operated.

a. TACFIRE _____

b. VFMED _____

c. DMD _____

d. BCS _____

e. BDU _____

f. None _____

PART II

Place an X in the column which best describes your opinion.

	Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
1. There was too little time allowed for the instruction.	______	______	______	______	______
2. There was too much time allowed for the instruction.	______	______	______	______	______
3. The platform instruction was clear and concise.	______	______	______	______	______
4. The platform instruction was confusing.	______	______	______	______	______
5. The objective of each lesson was clear from the beginning.	______	______	______	______	______
6. I understood all of the words used in the training.	______	______	______	______	______
7. The time allowed for training was just about right.	______	______	______	______	______
8. The instructions given by the instructors were confusing.	______	______	______	______	______
9. The equipment is easy to operate.	______	______	______	______	______
10. The equipment is too complex to learn in the time allowed.	______	______	______	______	______
11. The situations presented in the instructions were realistic.	______	______	______	______	______
12. The classes were well organized.	______	______	______	______	______
13. With the instructions I have received, I can now operate the FIST DMD.	______	______	______	______	______
14. I can perform a task by following exactly the directions given in the operator's manual.	______	______	______	______	______
15. The tasks in the manual are explained clearly.	______	______	______	______	______
16. I have no problem understanding the manual.	______	______	______	______	______

PART III

Indicate by a check mark which of the following operator procedures, or tasks, you have performed. Indicate those that were taught, but you did not perform, and indicate those tasks which were not taught.

	Performed	Taught, but Not Performed	Not Taught
1. Perform initial checks:			
a. Initial adjustment.	____	____	____
b. Equipment.	____	____	____
c. Power.	____	____	____
d. Communications and G/VLLD interface.	____	____	____
e. Transmission.	____	____	____
f. Addresses.	____	____	____
g. Authentication code list book.	____	____	____
2. Installation of internal battery pack.	____	____	____
3. Removal of internal battery pack.	____	____	____
4. External power connections:			
a. Vehicle battery.	____	____	____
b. Vehicle radio mount.	____	____	____
c. External battery pack.	____	____	____
5. FIST DMD interface connections:			
a. FM radio sets.	____	____	____
b. AM/SSB radio sets.	____	____	____
c. Crypto equipment.	____	____	____
d. Radio remote equipment.	____	____	____
e. G/VLLD.	____	____	____
f. Wire.	____	____	____
6. Operational checks.	____	____	____

	Performed	Taught, but Not Performed	Not Taught
7. Enter the following data into the FIST DMD:	___	___	___
a. Local address.	___	___	___
b. FIST DMD location.	___	___	___
c. Net status.	___	___	___
d. Net assignment.	___	___	___
e. Subscriber addresses.	___	___	___
f. Observers numbers.	___	___	___
g. Subscriber modes.	___	___	___
h. Observer locations.	___	___	___
i. Authenticator codes.	___	___	___
8. The following message formats:			
a. Standard fire request.	___	___	___
b. Adjustments.	___	___	___
c. Registrations.	___	___	___
d. Intelligence.	___	___	___
e. Information.	___	___	___
9. Mission buffers.	___	___	___
10. Message files.	___	___	___
11. Message transmission:			
a. Locally compounded.	___	___	___
b. Messages from received message queue.	___	___	___
12. Message reception.	___	___	___
13. Message copies file.	___	___	___
14. Mission data file.	___	___	___
15. Cleaning the DMD.	___	___	___
16. Troubleshooting.	___	___	___

PART IV

1. a. Did you have any problems learning how to operate the FIST DMD?

Yes____ No____

b. If yes, what problems did you have?________________________________

____

____

____

c. Did you solve the problem?

Yes____ No____

2. a. Do you feel that you can operate a FIST DMD under most conditions?

Yes____ No____

b. If no, under what conditions do you feel that you can not operate the FIST DMD? ____

____

____

____

3. Use the space below for any comments you may have concerning the FIST DMD or improving the training.

APPENDIX C

FIST DMD OPERATOR'S

END-OF-TEST QUESTIONNAIRE

APPENDIX C

FIST DMD OPERATOR'S

END-OF-TEST QUESTIONNAIRE

NAME:____ RANK:____________________

UNIT:____ SSAN:____________________

The following questions ask you about each task you learned during training. After discussing each task, you will have the opportunity to comment on any part of the training or on any task.

Please be serious, work carefully and give your honest answers about your experiences and your feelings.

Your observations will be used in making the training evaluation for this test.

<u>REMEMBER!! GIVE YOUR HONEST OPINION.</u>

PART I

This part of the questionnaire is exactly the same as part II of the after-training questionnaire. These questions pertain to the training only. Remember back to the training you had and answer these questions.

Place an X in the column which best describes your opinion.

	Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
1. There was too little time allowed for the instruction.	____	____	____	____	____
2. There was too much time allowed for the instruction.	____	____	____	____	____
3. The platform instruction was clear and concise.	____	____	____	____	____
4. The platform instruction was confusing.	____	____	____	____	____
5. The objective of each lesson was clear from the beginning.	____	____	____	____	____
6. I understood all of the words used in the training.	____	____	____	____	____
7. The time allowed for training was just about right.	____	____	____	____	____
8. The instructions given by the instructors were confusing.	____	____	____	____	____
9. The equipment is easy to operate.	____	____	____	____	____
10. The equipment is too complex to learn in the time allowed.	____	____	____	____	____
11. The situations presented in the instructions were realistic.	____	____	____	____	____
12. The classes were well organized.	____	____	____	____	____
13. With the instructions I have received, I can now operate the FIST DMD.	____	____	____	____	____
14. I can perform a task by following exactly the directions given in the operator's manual.	____	____	____	____	____
15. The tasks in the manual are explained clearly.	____	____	____	____	____
16. I have no problem understanding the manual.	____	____	____	____	____

PART II

Now that you have had field experience with the FIST DMD, you have probably gained more knowledge in operating and in maintaining it.

Please place an X in the PERFORMED column if you performed the task in the field during the test. Under HOW WELL PERFORMED put a number from the code below in the space by the X. If you did not perform the task in the field, leave both spaces blank.

Use the following code numbers.

CODE NO.	HOW WELL PERFORMED
1	Needed a lot of help to perform task.
2	Needed some help to perform task.
3	Needed no help to perform task, but was slow.
4	Performed task quickly with no help and no problems.

	PERFORMED	HOW WELL PERFORMED
1. Performed the following initial checks:		
a. Initial adjustment.	________	________
b. Equipment.	________	________
c. Power.	________	________
d. Communications and G/VLLD interface.	________	________
e. Transmission.	________	________
f. Addresses.	________	________
g. Authentication code list book.	________	________
2. Installed internal battery pack.	________	________
3. Removed internal battery pack.	________	________
4. Made the following External power connections:		
a. Vehicle battery:	________	________
b. Vehicle radio mount.	________	________
c. External battery pack.	________	________

CODE NO.	HOW WELL PERFORMED
1	Needed a lot of help to perform task.
2	Needed some help to perform task.
3	Needed no help to perform task, but was slow.
4	Performed task quickly with no help and no problems.

	PERFORMED	HOW WELL PERFORMED
5. Made the following FIST DMD interface connections:		
a. FM radio sets.	______	______
b. AM/SSB radio sets.	______	______
c. Crypto equipment.	______	______
d. Radio remote equipment.	______	______
e. G/VLLD.	______	______
f. Wire.	______	______
6. Made the FIST DMD Operational checks.	______	______
7. Entered the following data into the FIST DMD:		
a. Local address.	______	______
b. FIST DMD location.	______	______
c. Net status.	______	______
d. Net assignment.	______	______
e. Subscriber addresses.	______	______
f. Observers numbers.	______	______
g. Subscriber modes.	______	______
h. Observer locations.	______	______
i. Authenticator codes.	______	______
8. Used the following message formats:		
a. Standard fire requests.	______	______
b. Adjustments.	______	______
c. Registrations.	______	______
d. Intelligence.	______	______
e. Information.	______	______

CODE NO.	HOW WELL PERFORMED
1	Needed a lot of help to perform task.
2	Needed some help to perform task.
3	Needed no help to perform task, but was slow.
4	Performed task quickly with no help and no problems.

	PERFORMED	HOW WELL PERFORMED
9. Used the mission buffers.	______	______
10. Used the message files.	______	______
11. Made the following message transmissions:		
a. Locally compounded.	______	______
b. Messages from received message queue.	______	______
12. Received FIST DMD messages.	______	______
13. Used the message copies file.	______	______
14. Used the mission data file.	______	______
15. Cleaned the DMD.	______	______
16. Used troubleshooting procedures on the FIST DMD.	______	______

17a. Do you feel that you can operate and maintain the FIST DMD under most conditions?

Yes______. No______.

b. If No, what is the problem? ______________________________

____

____

18a. Do you have any problems operating and maintaining the FIST DMD because of inadequate training? Yes_____. No_____.

b. If Yes, what are the problems?______________________________

____

____

19. Use the space below for any comments you may have on the training you received, on the FIST DMD itself, or on the operation and maintenance of the FIST DMD.

____

____

____

APPENDIX D

LESSONS LEARNED FROM

THE FIST CPXRF EXPERIMENT

APPENDIX D. LESSONS LEARNED FROM THE FIST CPXRF EXPERIMENT

A. Scenarios

Scenario definition is still very subjective. For this experiment a scenario was defined to be a time ordered list of digital messages, and in this case, messages that would be received by the FIST HQ from its platoon forward observers (FO) using TACFIRE Digital Message Devices (DMD). It was surprising that no definition of "intensity" could be found that was given in terms of number of fire missions (FM) or messages per hour. Hence, a "reasonable" guess had to be made: Low Intensity - 1 Fire Mission per FO per hour, Medium - 2 FM/FO/hour, and high - 3 FM/FO/hour. The number of Artillery Target Intelligence (ATI) messages was varied inversely from the FMs, and an Immediate Smoke mission was added to each medium and high intensity cell (each cell was 2 hours long).

Because cells of the same intensity were to be compared, several other criteria were imposed on the scenario to insure that task loading on the FIST HQ didn't vary significantly between cells of the same intensity. The ratio of Fire For Effect (FFE) to Adjust Fire (AF) missions was chosen as 2:1 (as per Ft. Sill's direction), the number of adjustments in each AF mission was chosen as three, and one fire mission in each 2-hour cell was designated as urgent rather than normal priority. After the scenario was received, it was realized that the time interval between fire missions was also a significant factor that influences the loading on the FIST HQ. Since this timing wasn't specified in the scenario definition, all the fire mission time-tags were changed manually so that the intervals between the fire missions were the same for each cell of the same intensity. This was a time consuming procedure (60 man-hours). Some factors that were not analyzed in the first CPX experiment (but perhaps should have been) were the ranges to the targets, the target descriptions, and how often or which targets were in range of the available fire support assets. These factors would certainly affect the FIST HQ perception of the threat and perhaps the urgency attached to tasks, both of which might influence the results of tests like this one.

The process of verifying that the large, 144-hour scenario contained what was requested could only be achieved practicably through automatic means. The scenario was delivered on computer tape and loaded into the BRL computer(s) where it could be manipulated with the many standard software packages included with the UNIX Operating System. Several other programs were written to examine the database and display information concerning the factors listed above. (Most of these programs were written in a convenient pattern scanning and processing language named AWK.)

The messages in the scenario had to be converted from a "pseudo TACFIRE" format to the "Fixed Format" used by DMDs. The program written to do this was "table driven." This type of program is relatively quick to write and fast in execution, however, it is intolerant to errors; therefore, any deviation from the expected input format produced an error. There were many format errors in the input database (e.g., the abbreviation for a target disposition, DISPO, was often missing the "I," DSPO) that required manual alterations, an unexpected time consuming task on the large database.

B. Simulator Software

The two simulator programs, FOSCE (Forward Observer SCEnario) and FDS/MFDS (Fire Direction Simulator/Mortar FDS) interactively simulated both tactical equipment and its human operators. FOSCE mimicked the actions of the platoon forward observers that work for the FIST HQ while the FDS programs simulated generic artillery battalion and mortar fire direction centers, respectively, executing fire missions. It had to be determined exactly how the simulators should react to the many different events that could occur during the scenario. This required group participation and each possible event had to be discussed. Many different factors were taken into consideration such as tactical realism, physical constraints, and the test design. Most of the events could be handled in more than one way and a decision had to be made (that was sometimes arbitrary) as to how the simulator should react. This problem was compounded by the introduction of degraded communications. Even for a simple adjust fire mission, over 30 randomly selected messages could be deleted for 30% communications degradation level, and the simulators had to adjust to react to this (note Figure 5).

Some operations that are normally handled via voice with TACFIRE had to be implemented using digital means for the simulators. For example, fire missions from FOSCE could be rejected or ended by sending a freetext message "MISSION REJECTED." If a target number had been assigned, FOSCE would send an End Of Mission and Surveillance (ES) message and then wait for the next mission. An ES message would cause the FDS or MFDS to end a mission already in progress.

Despite the capability built into the simulators to handle degraded communications, "deadlock" situations still occurred. This would happen when a message that was lost from one simulator was required by another simulator to continue processing. A common example of this occurred when a Subsequent Adjust message from FOSCE, which was to be relayed automatically to the FDS by the FIST DMD, was lost during the relay. Although the FIST DMD warned the operator when such a situation existed, the warning was sometimes missed, inadvertently deleted, or more urgent problems forced a delay in reacting to the warning and it was forgotten. Hence, FOSCE was content because the message it sent was acknowledged by the FIST DMD; FOSCE was waiting for a SHOT message. But the Subsequent Adjust message for which the FDS was waiting never arrived; both simulators were waiting for something from the other. It was noted by a Field Artillery School instructor that this situation is not uncommon in the real world. To solve this problem, the simulators had to be able to respond to queries from the FIST HQ. Freetext fire mission "status" messages were defined so that the FIST HQ could inquire about the current status of a fire mission by referencing either a Target Number or an Observer Identification number and DMD mission buffer. These inquiries could be sent to either the FOSCE or FDS programs, and based upon the response, the FIST HQ could take action to fix the deadlock situation or end the mission.

During the discussions concerning the reactions of the simulators to missing or erroneous messages, it became quite obvious that it is easier to teach an applications expert to program than the reverse.

C. Real Time Display

A real time display program, named ADIS (ACE Display and Information System), allowed the controllers to see all the messages as they passed between real and simulated players. The display, along with a chronological listing of the scenario, was used by the controllers to track the progress in the test cells. This proved to be essential in identifying and collecting information on unusual events, which normally developed quickly and were hard to trace. This was even more important during the extensive debugging phase of the experiment. The Field Artillery School instructor also found it helpful in following the progress of the students during the training phase.

Special messages were developed to allow the simulators to add information to the database. These messages were sent to reserved addresses so that they could be easily identified in the database later. The simulators did not expect acknowledgement for these messages. Some of these messages were displayed by ADIS for the controllers to identify special events, such as a simulator not receiving an acknowledgement after four transmission attempts, or the reception of a duplicate fire mission by the FDS (i.e., same as one already in progress). Other messages were simply entered into the database for use during data reduction. These were typically messages that announced that a particular simulator was beginning or ending a fire mission. They identified the time that the simulators believed a fire mission started or ended regardless of the actions of the live players. These messages were used by the data reduction software to identify when events actually began or ended despite the confusion caused by the communications degradation.

The capability to start or end a cell anywhere within that cell was implemented to allow the controller to restart a cell if a computer hardware malfunction was encountered, thus eliminating the need to redo a complete cell. This capability was utilized only two or three times during the entire experiment but it did save several hours of test time.

A camera and microphone were placed in the FIST vehicle mock-up to record the face of the FIST DMD and the crew's conversations. These were simultaneously recorded with the ADIS Display so that a complete picture could be obtained at a later time to identify specific parts of the scenario that caused problems and the events that led up to them. When the ADIS display was combined with the actual actions of the crew, it presented a comprehensive picture of how the test group (FIST) interacted with the entire system.

D. Hardware

The Bit Boxes (MODEMs that convert between Frequency Shift Keyed (FSK) TACFIRE signals and standard RS-232 signals) do not prevent collisions from occurring; therefore, even "perfect" communications, wasn't. The FIST DMD contained a "net monitoring" function to reduce message collisions. This feature was not implemented in the Bit Boxes, and it was originally believed that the lack of this was the reason for most of the collisions; however, this was not the case. Of the 4764 messages that were sent during the second half of the experiment under "perfect" communications conditions, 109 had to be sent more than once. There was only one collision resulting from two original messages being transmitted simultaneously; the rest were collisions between a message and an acknowledgement (ACK). A look at these messages revealed that 3 out of 4 of them were sent from the FIST DMD (the rest were sent from the simulators). This exposed a basic problem, not in the hardware, but in the ACE software. The actual TACFIRE hardware transmits ACKs immediately; however, those in the experiment normally took 2 to 3.5 seconds. This acknowledgment delay was more than enough to trigger the FIST DMD to retransmit the message. Hence, 3 out of 4 of these message collisions would not have happened in the "real world," or only about 25 of 4700 messages would have actually collided if the FOs were not listening to the net before transmitting. Whether the delay in the ACK was caused by the ACE Ether program or the simulators is not known; however, a new Ether program is being developed that will solve this problem, and the simulators can be modified to send acknowledgements faster.

E. Data Reduction

Reducing the 45,000 messages recorded in this 144-hour experiment into meaningful information was not a simple task. The reaction of the FIST DMD operators to degraded communications often produced results that were unexpected or difficult to trace. As mentioned earlier, the slight delay in acknowledgement messages (ACK) coupled with the heavy message traffic often made it difficult to match ACK's to messages after the fact.

Human analysis was still required to retrieve many results. Many of the standard programs available with the Unix Operating System were invaluable to assist in this work; however, a great deal of knowledge about the fire support (and TACFIRE) system is required to trace and identify many problems. Much smarter data reduction programs will have to be developed, probably using artificial intelligence techniques, in order to automate the more complex data reduction problems.

F. FIST Operations

Missing an ACK is more detrimental than missing a message. For example, suppose an acknowledgement (ACK) is sent from player B in response to a message received from player A. If that ACK is not received, then first, player A believes that his message was not received (he received no ACK), and second, player B thinks everything is going well since he received a message and has no way of knowing that his ACK did not get through. Consequently, player B continues processing as usual, but player A keeps trying to get the message to player A, clogging the radio net, and filling player B's message queue full of duplicate messages. If this happens to many people in the system, the extra loading can be significant, especially if player B happens to be the one with whom everyone else wants to communicate, (e.g., TACFIRE).

The FIST could continue fire support coordination operations through 30 percent communications degradation once trained to do so. A key lesson they learned was to use a "wait and see" technique after failing to get an ACK to a message after four tries. Usually it is the ACK, rather than the message, that is lost. (This situation could become quite common when a mobile observer with a low power radio is communicating with a station that has a good antenna and a high powered radio, for example, an FDC.) Hence, by waiting a few minutes the expected response message was received even though the ACK never was. The FIST also learned to use the "status" messages to find and fix deadlock situations thus resorting to digital, rather than voice, means to correct problems. However, they still depended upon paper and pencil to keep track of what target numbers were active along with the progress of each mission.

Many software enhancements were recommended for the FIST DMD; nearly all of th have been implemented by the developers and added to the FIST DMD specificati (with its reference number):

3.2.1.19 - Built-in relay mode can be disabled.

3.2.1.22 - Multiple addressing capability (as in HELBAT-8 FIST DMD has been added).

3.2.1.25 - Transmission Repeat Number (TRN) is reset to zero when forwarding a m sage through the FIST DMD and when the FIST DMD authenticators are used.

3.2.1.26.3 - Duplicate messages in the message queue are eliminated.

3.2.1.26.3.5 - A special message has been added to alert the FIST DMD operator wher message is received from an unknown source.

3.2.1.34 - "Rounds Complete" message (FO Command) is sent to the forward obser via a free text message (until the current DMD is upgraded to EPROMS thus becomi reprogrammable).

3.2.1.37 - Mission denial feature has been added to the Message To Observer (MTO).

NOMENCLATURE

ACE	Artillery Control Environment
ACK	Acknowledgement (message)
ADIS	ACE display and Information System
ADP	Automatic Data Processing
ATI	Artillery Target Intelligence
BBP	Bit Box Interface Program
BCS	Battery Computer System
BCU	Battery Computer Unit
BDU	Battery Display Unit
bn	battalion
btry	battery
C^3	Command, Control and Communication
CH	Chief
Cmd	Command
CO	Company
CPU	Central Processing Unit
CPXRX	Command Post Exercise Research Facility
CRT	Cathode Ray Tube
DARCOM	US Army Materiel Development & Readiness Command
DMD	Digital Message Device
EOM	End of Mission (Message)
EOT	End of Transmission
ES	End of Mission and Surveillance (Message)
EW	Electronic Warfare
ETHER	Intra-computer Communications Network Software
FDC	Fire direction Center
FDS	Fire Direction Simulator
FFE	Fire for Effect (Mission)
FM	Fire Mission
FIST	Fire Support Team
FISTV	FIST Vehicle
FO	Forward Observer
FOSCE	Forward Observer Scenario Program
FR	Fire Request
FR GRID	Call to Fire using Grid Coordinates for Target Location
FSE	Fire Support Element
FSK	Frequency Shift Keying
GDU	Gun Display Unit
HELBAT	Human Engineering Laboratory Battalion Artillery Test
HQ	Headquarters
HTB	Howitzer Test Bed
LT	Lieutenant
MOP	Measure of Performance
MFDS	Mortor Fire Direction Simulator
MSG	Message
MTO	Message to Observer (Message)
RDT&E	Research, Development, Testing and Evaluation
SA	Subsequent Adjust
SCORES	Scenario Oriented Recurring Evaluation System
TACFIRE	Tactical Fire Direction System
TRADOC	US Army Training and Doctrine Command

USABRL	US Army Ballistic Research Laboratory
USAFAS	US Army Field Artillery School
USAHEL	US Army Human Engineering Laboratory
VFMED	Variable Format Message Entry Device

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